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Hydrogeology and water resources of the Missoula basin Montana

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HYDROGEOLOGY AND WATER RESOURCES
OF THE MISSOULA BASIN, MONTANA

By

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ABSTRACT

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Hydrogeology and water resources of the Missoula Basin, Montana (114 p.)

Changing patterns of water use in the Missoula Basin over the last twenty-five years have greatly increased the consumption of groundwater. During the water year 1977-1978, 37 observation wells were monitored to measure seasonal water table fluctuations; data on geology, hydrology, soils, climate, physiography, demography, and water use were analyzed to evaluate the hydrogeology and to calculate the current water budget.

Three types of geologic units furnish water to wells - Pliocene-Holocene alluvium on the valley floor; confined sand and gravel layers within Oligocene-Miocene sediments under the valley floor and in the foothills; and fractured Precambrian bedrock. The combined storage of readily available groundwater in the 3,000 feet of Pliocene-Holocene alluvium and Oligocene-Miocene sediments is about 376,400 acre-feet, of which about 95% is in the upper 200 feet. Groundwater levels fluctuate on average about 10 feet a year; they are most often at their maximum in June and at their minimum in April. Groundwater in most years is less than 100 feet deep. It is consistently of good quality, except where septic tank failures locally pollute the Oligocene-Miocene aquifer in the foothills. Groundwater flows predominantly southwestwards towards the Clark Fork and Bitterroot Rivers, which, however, are influent within the basin.

Total streamflow into the basin equals 4,012,375 acre-feet/year; streamflow from the basin annually equals 3,971,683 acre-feet. Most of the precipitation, which annually is 12-15 inches, evaporates or is used by plants before infiltrating to the water table. Total water consumption annually amounts to about 55,000 acre-feet after return of some water to the ground and streams from irrigation, sewage outflow, and municipal pipeline losses. Irrigation recharge annually is about 8,800 acre-feet. The total outflow from the basin currently exceeds inflow by about 21,500 acre-feet, resulting in local, mostly seasonal depressions of the water table. The prevention of future basinwide water table declines requires the location of public supply and irrigation wells in areas of reliably rapid recharge, such as the Clark Fork floodplain. Utilization of the Oligocene-Miocene and Precambrian aquifers should be discouraged because of small sustained yields from these units.

R. R. Curry

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INTRODUCTION

Statement of Problem

The total amount of water available for consumption regionally varies as water use patterns change. The Missoula Basin, over the last twenty-five years, has experienced a large population increase, a significant shift from rural to urban land use, and an increasing reliance upon groundwater to meet consumptive needs. Although water supplies at present appear to adequately meet the growing demands for water, the possibility of shortages in the future exists unless policies are developed to accomodate the limitations of the area's surface and ground water resources. This requires an accurate evaluation of these resources based on integration of all existing geologic, hydrologic, and demographic data for the area. Past geologic studies of the Missoula Basin have not definitively established the spatial relationships of water-bearing strata, which is critical to assessing groundwater resources. Although much data exists on surface water resources and water use, it has not been synthesized to assess supply and demand.

This study will reexamine the geology of the Missoula Basin as revealed in surface exposures and drilling. On the basis of water inflow and outflow and calculated hydrologic properties of the geologic units, the total annual change in storage and the storage potential of the basin will be calculated.

Previous Investigations

The geology of the area has been described by Alden (1953), Nelson and Dobell (1961), McMurtrey and others (1965), Hall (1968), Weber and Associates (1978), and Vander Poel (1979). Hydrologic properties of regional aquifers are calculated and discussed by McMurtrey and others (1965), Botz (1969), Grimestad (1977), and Konizeski and Alt (1972). Water levels in observation wells are recorded in Brietkrietz (1964), Reed and McMurtrey (1970, 1968), and in unpublished data from Montana Department of Natural Resources and U.S. Geological Survey. Water quality data are available in McMurtrey and others (1965) and Juday and Keller (1979). Soil hydrologic properties are found in Missoula County Planning Board (1974), U.S. Soil Conservation Service (1972, 1971), Brietkrietz (1964), and well logs on file with the Montana Department of Natural Resources and Conservation. Precipitation and surface water data are published by the National Oceanic and Atmospheric Administration and U.S. Geological Survey, respectively. Information on local water use is not readily available, but estimates can be made from Montana State Engineer (1960), Missoula County Planning Board (1974), and unpublished data available through the U.S. Soil Conservation Service, Montana Power Company, Western Water Company, Missoula Sewage Treatment Plant, local businesses, and irrigation districts.

Present Methods of Investigation

A literature search was conducted to assemble all available reports on the area's geology, hydrology, soils, climate, physiography, demography, and water use. Unpublished data were also collected.

The geology of the area was compiled from well logs, published maps and discussions, uranium exploration logs, and independent investigations. This information was portrayed on a base contour map (1:24,000) prepared by Stensatter, Druyvestein, and Associates and in cross sections.

Hydrologic properties of geologic units were calculated from pump test data and cited references according to methods described in Jacob (1963a, 1963b). Aquifer dimensions were determined from well logs, and the distribution of water-bearing units was shown on a 1:24,000 base map.

The configuration and behavior of the water table were determined by monitoring 37 observation wells with an electric probe during the water year 1977-1978 and by analyzing fluctuations of water levels in an observation well monitored by the U.S. Geological Survey since 1959. Well hydrographs and water table maps were prepared for the period of investigation.

The amount of available groundwater in storage was calculated from aquifer dimensions and internal properties. Rates and quantities of groundwater movement through the basin were calculated using Darcy's Law, which relates discharge to transmissivity, water table gradient, and width of flow section.

Precipitation influx to storage was determined from recorded precipitation in the basin minus estimated evaporation and transpiration losses. Evapotranspiration loss estimates were based upon land use, moisture requirements of vegetative cover, and potential evaporation (which depends upon climate).

Stream inflow and outflow were determined from U.S. Geological Survey records of gaged streams and the estimated discharge of ungaged streams. The latter quantity was determined by relating the mean discharge, drainage area, and precipitation influx of a gaged stream (Rattlesnake Creek) to the same parameters for ungaged streams flowing into the basin. Hillside runoff to the Missoula Basin was determined from a precipitation/runoff relationship described in U.S. Soil Conservation Service (1971).

Non-agricultural water use was estimated from a relationship between consumption per person or business and the number of persons or businesses in Missoula, as determined from Montana Power Company records, estimates provided by Western Water Company and some commercial users, and demographic data provided by the Missoula County Planning Board. Water usage by livestock was calculated from the estimated number of horses, cattle, and sheep in the Basin (Missoula County Extension Service, oral communication) and livestock daily moisture requirements. Irrigation use was determined from the irrigated acreage, crop moisture requirements, net precipitation, irrigation method and efficiency, and site conditions (soil and slope).

The current annual change in storage is the difference between water inflow and outflow. Inflow includes net precipitation, stream recharge, hillside runoff, irrigation seepage, sewage return, and municipal supply losses. Outflow includes stream discharge, irrigation diversion, groundwater seepage, and consumption. Most of this data has been interpreted, and because assumptions used in the interpretations may be oversimplified or slightly erroneous, reported values are probably accurate to no more than two or three significant figures.

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REGIONAL SETTING

Physiography

The Missoula Basin forms the southeastern end of the Missoula-Ninemile Valley, which is situated in the Northern Rocky Mountains physiographic province (Figure 1). The valley, in its entirety, is a closed intermontane depression which trends N55° W for about 50 miles and tapers in width from 8.5 miles at its southeastern end to about 1 mile at its northwestern end. The valley is bordered on the north by the Rattlesnake Hills; on the east by the Sapphire Mountains; on the south by the Bitterroot Range; and on the west by the Ninemile Divide. The Missoula Basin is separated from the rest of the valley by a ridge of partially consolidated sediments and bedrock extending from the Missoula County Airport to Council Hill. The Missoula Basin including the surrounding hills, is approximately 195.4 square miles in area.

The mountains around Missoula are highest in the Rattlesnake Hills, where peak elevations are commonly 6,000 to 8,000 feet. Point Six rises to 7,929 feet in elevation; Sheep Mountain, to 7,650 feet in elevation. Although some peaks in the Sapphire and Bitterroot Ranges are above 6,000 feet, these mountains are commonly 4,000 to 6,000 feet in elevation. The highest peak in the Bitterroot Range west of Missoula, Blue Mountain, is 6,460 feet in elevation;

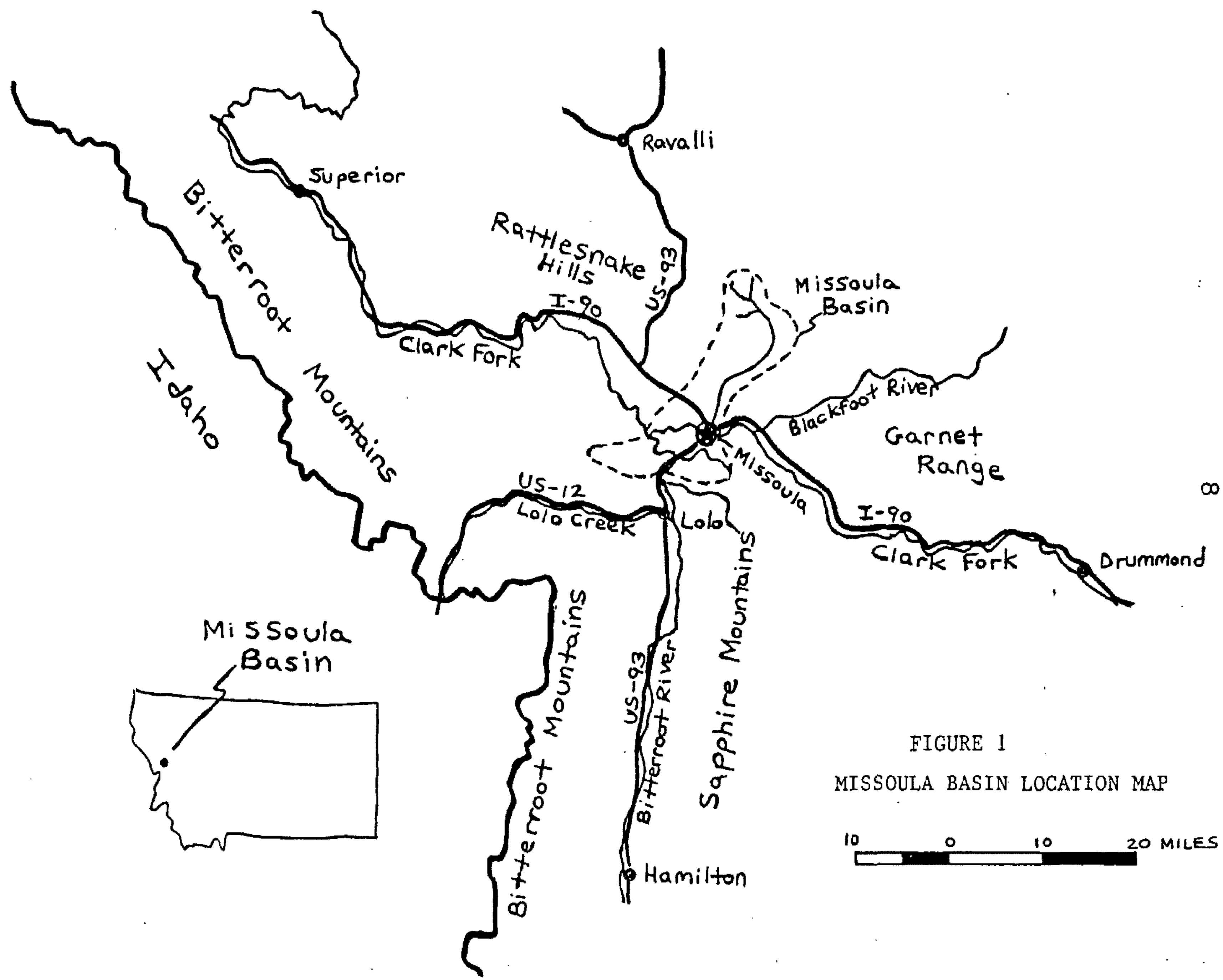


FIGURE 1

MISSOULA BASIN LOCATION MAP

Mount Dean Stone in the Sapphire Range southeast of Missoula is 6,203 feet in elevation.

The valley floor is drained by the Clark Fork and Bitterroot Rivers, which have superimposed themselves upon over 2,500 feet of unconsolidated to partially consolidated sediments. The Clark Fork River enters the basin in the northeast corner, through the Hellgate Canyon. The river flows southwesterly about 6 miles, meeting the Bitterroot River about 4 miles west of Missoula, and then flows northwestward another mile before leaving the basin at Council Hill. From the Hellgate Canyon to Council Hill, the Clark Fork descends in elevation from 3,180 feet to 3,090 feet, along an average gradient of 12 feet per mile. The Bitterroot River enters the valley in the southeast corner of the basin through a bedrock gap, flowing towards the Clark Fork along a gradient of 6 feet per mile. Smaller streams entering the basin include Rattlesnake Creek, O'Brien Creek, Pattee Creek and Grant Creek; the latter two seep into the valley alluvium or are diverted before reaching the main streams during most years.

Two stream terraces rise above the present Clark Fork and Bitterroot flood plains. These terraces are separated from each other and the present flood plains by 20 foot high scarps. The upper of these terraces slopes northwestward from 3,223 feet in elevation at the University of Montana campus to 3,140 feet in elevation below Council Hill.

Foothills with 100 to 300 feet of relief rise above the north, east, and southeast sides of the basin and slope gradually to the base of the mountains. McCauley Butte, a 200 foot high outlier of bedrock, stands above the Bitterroot flood plain near the mouth of the Clark Fork. The ridge forming the northwest side of the basin is 40 to 60 feet high, up to 2 miles wide, and 3,200 feet in elevation at its highest point.

Climate

The climate is dominated by relatively warm and moist Pacific maritime air, which during the winter, is periodically displaced by cold Arctic air moving in through the Hellgate Canyon east of Missoula. The average temperature in January, the coldest month, is 22.7°F; in July, the warmest month, it is 71.8°F (USDA, 1977). January temperatures range from -16°F to 44°F; July temperatures, from 46°F to 100°F. Peak snowmelt is during late April and early May. There are 137 frost-free days a year, on average.

Precipitation is strongly influenced by the Bitterroot Range, which intercepts much of the moisture in the prevailing westerly air flow. The annual precipitation at Missoula is 12 to 15 inches, whereas surrounding peaks receive up to 60 inches annually (Figure 2). Annual precipitation falling on the irrigated part of the basin,

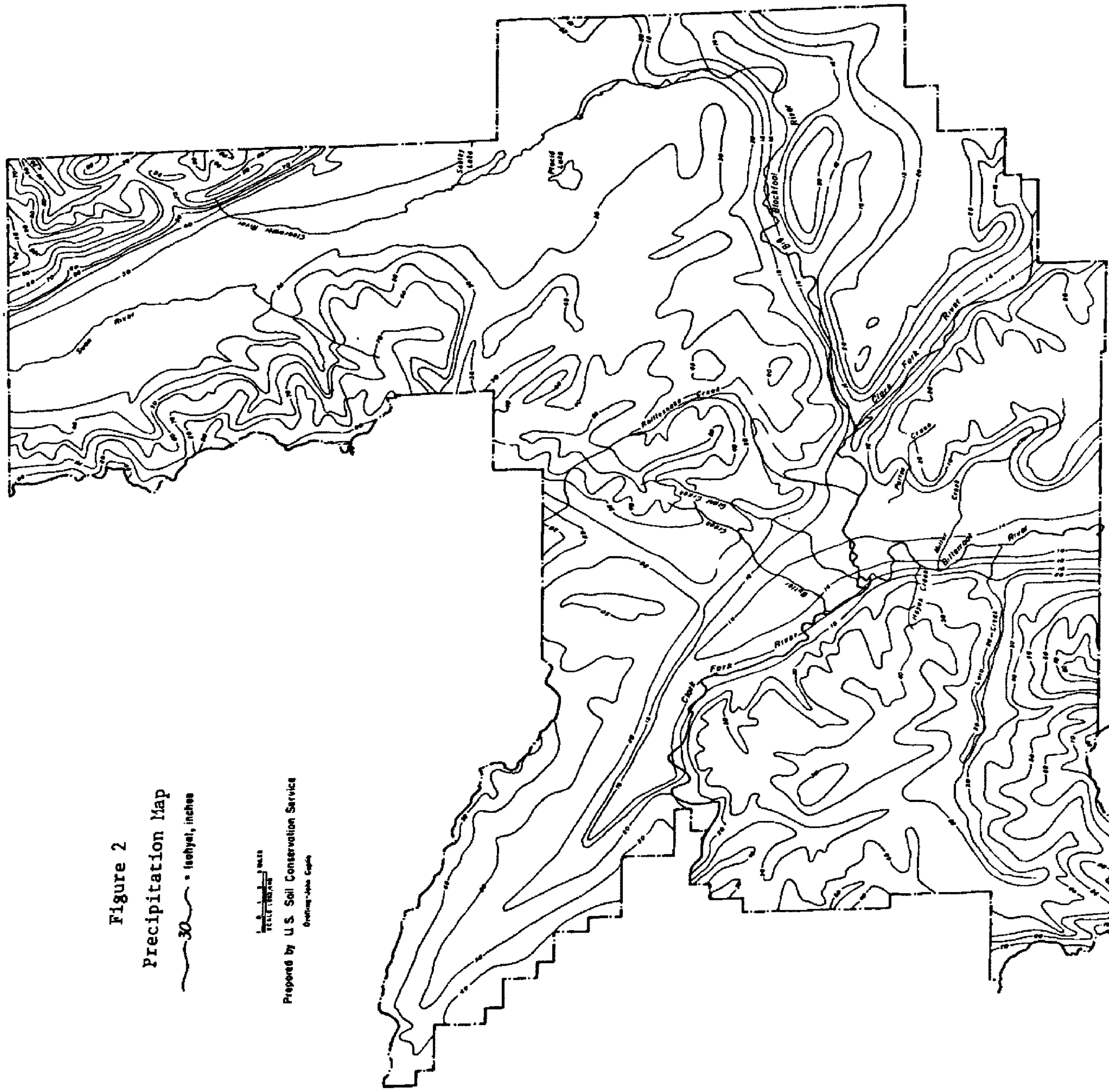


Figure 2
Precipitation Map

30 = Isohyet, inches

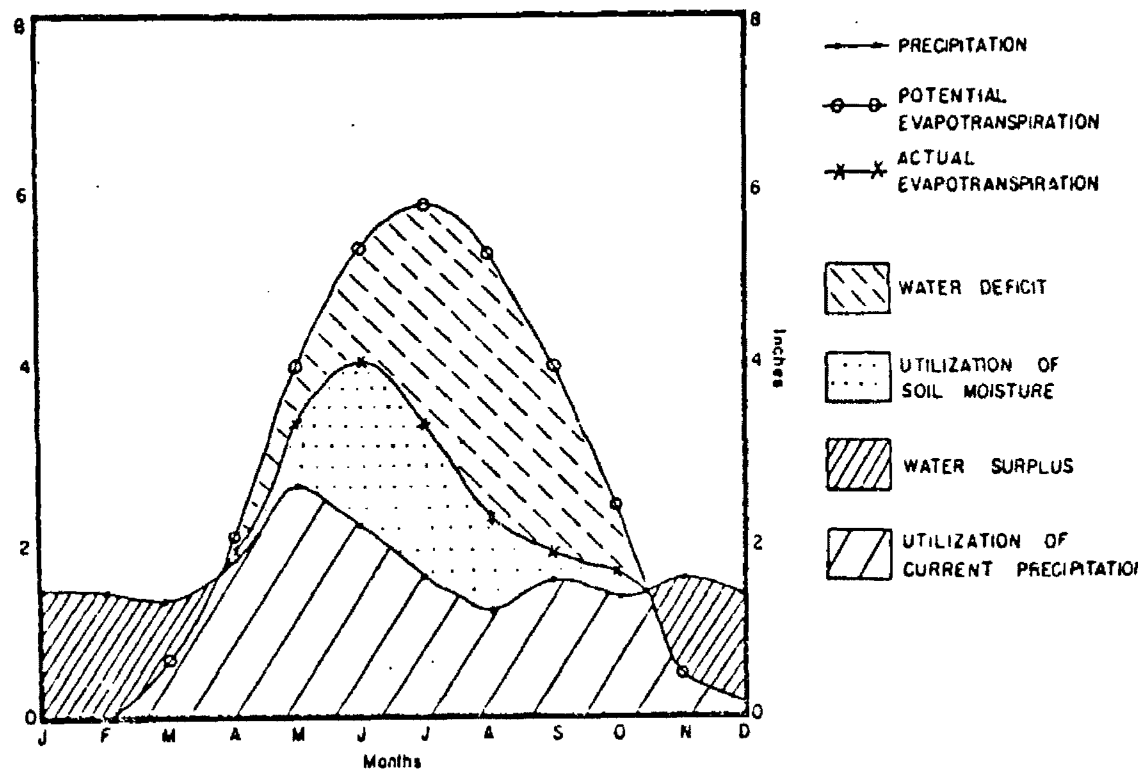
Prepared by U.S. Soil Conservation Service about 22,643 acres, is approximately 24,775 acre-feet; annual precipitation over the entire basin is about 261,692 acre-feet. Peak precipitation occurs during May and June, with almost daily shower activity during that time. February and March are the driest months.

Evaporation and plant transpiration greatly diminish the amount of precipitation actually infiltrating the soil and reaching the water table (i.e., the upper surface of the zone of saturation.) Figure 3 shows the potential evapotranspiration in the Missoula area as a percentage of monthly precipitation. Potential evapotranspiration is a function of temperature, solar radiation, relative humidity, and wind velocity. During January and February, 100 percent of the precipitation falling in the Basin potentially reaches the water table, but during the remainder of the year, 88 percent evaporates directly or is used by plants in transpiration. From April to October, no precipitation reaches the water table through infiltration.

The amount of precipitation used by plants during the growing season (late April to early October) can be determined if the amount of vegetated land and the dominant types of vegetation growing upon it are known. From Missoula County Planning Board (1974), it is estimated that 10,942 acres within the irrigated part of the Missoula Basin are grass-covered, 4,975 acres are covered with trees or alfalfa (which have similar moisture requirements), and 6,726 acres

FIGURE 3.
WATER BALANCE DIAGRAM

MISSOULA, MONTANA



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Geography Department

are covered with asphalt, concrete, or buildings (which are presumed, simplistically, to evaporate all precipitation falling upon them during months of the year when potential evaporation is greater than zero). Based on the amounts of grass and alfalfa covered land and the moisture requirements of these plant species (U.S. Soil Conservation Service, unpublished), it is estimated that plant transpiration annually consumes 28 percent of the precipitation falling on the Missoula Basin.

Evaporation, which equals potential evapotranspiration minus transpiration, annually diminishes the precipitation influx by 48.2 percent. Net precipitation, which equals gross precipitation minus potential evaporation and transpiration, equals 5,902 acre-feet per year, or 23.8 percent of gross precipitation (Table 1).

Table 1 Missoula Basin Climatic Data[1]

Month	Gross Precipitation inches	Gross Precipitation acre-feet	Potential Evaporation acre-feet	Transpiration acre-feet	Net Precipitation acre-feet
January	0.99	1868	0	0	1868
February	0.76	1434	0	0	1434
March	0.63	1189	803	0	386
April	1.00	1887	1613	274	0
May	1.88	3548	1909	1639	0
June	1.96	3698	1799	1899	0
July	0.94	1771	734	1037	0
August	0.85	1604	725	879	0
September	1.01	1906	978	928	0
October	0.95	1793	1521	272	0
November	1.07	2019	1044	0	975
December	1.09	2057	818	0	1239
Total	13.13	24,774	11,944	6,928	5,902

[1]Calculated from USDA Soil Conservation Service and University of Montana Geography Department data.

Geology

Stratigraphy

The Missoula Basin contains up to 3,000 feet of Tertiary and Quaternary sediments overlying a highly eroded surface of Precambrian rock (McMurtrey and others, 1965). The Valley fill is indicated by gravity data to be thickest below the Missoula County Airport and the area around the Missoula Sewage Treatment Plant (McMurtrey and others, 1965, Plate 2). The geology of the basin is summarized in Table 2 and portrayed in Figures 4 and 5 and Plate 1.

Precambrian Belt Supergroup - Continental and shallow marine sedimentary rocks of the Precambrian Belt Supergroup form the mountains around the Missoula Basin and outliers like McCauley Butte within the valley and foothills. McMurtrey and others (1965) estimate the Belt rocks to be 10,000 feet thick in this area. Hall (1969) estimates them to be at least 25,000 feet thick. Argillite, siltite, and quartzite of the Missoula Group predominate over limy argillite, impure limestone, and quartzite of the older Wallace Formation. The distribution of these units is shown on maps by Nelson and Dobell (1959), Hall (1969), and Weber and Associates (1978). The Belt Supergroup is probably between 0.8 and 1.6 billion years old, as suggested by radiometric age dates of the sills and dikes intruding it and the whole-rock and individual mineral ages obtained for Belt

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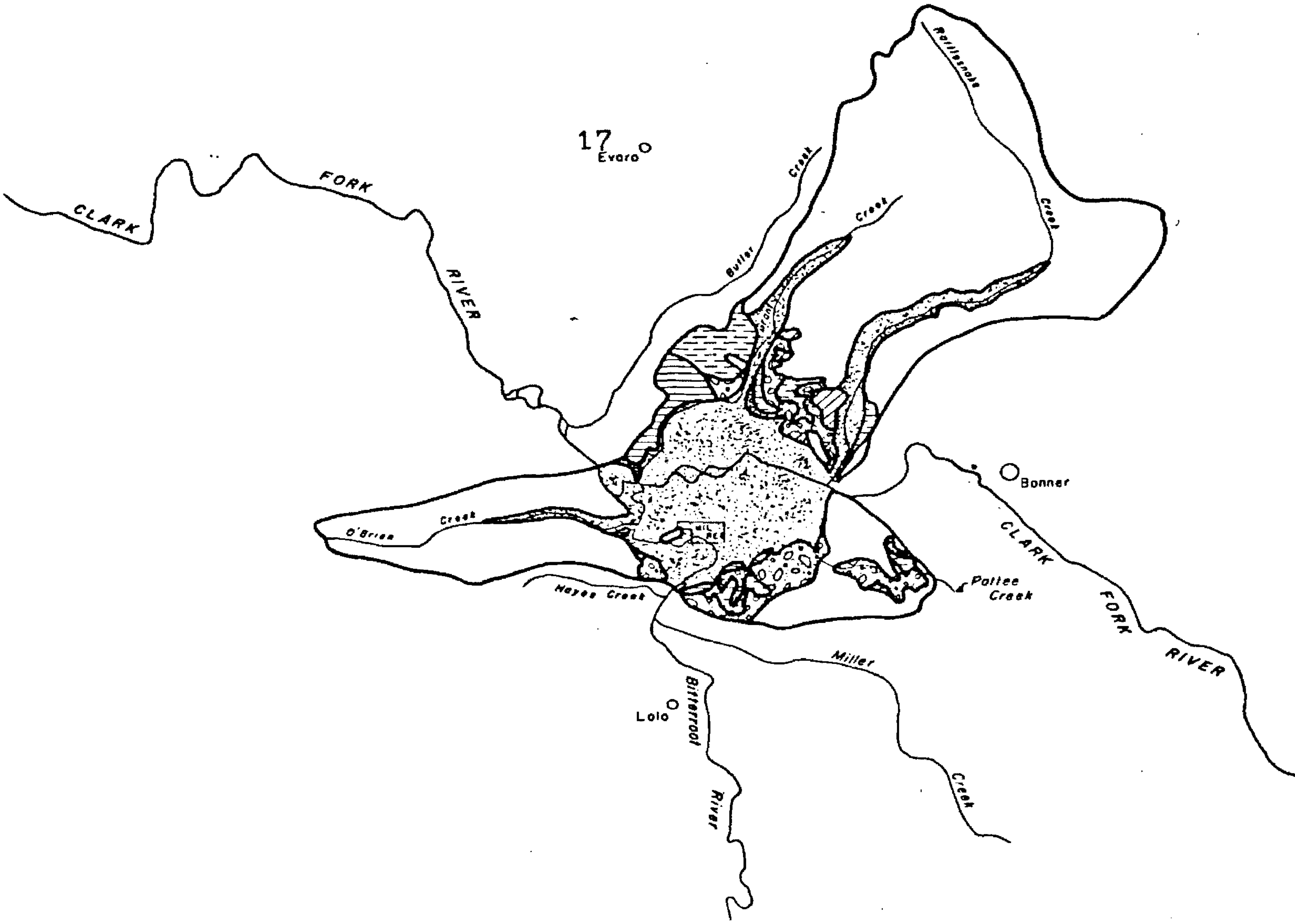

Figure 4

GENERALIZED GEOLOGY OF MISSOULA BASIN

1 0 1 2 3 Miles
SCALE 1:253,440

Legend

Qls Pleistocene-Holocene landslide deposits

Qa Pleistocene-Holocene sand and gravel; includes channel, floodplain, and alluvial fan deposits

Ql Pleistocene lake beds-varved silt and clay, with subordinate sand

QTg Pliocene-Pleistocene sand, gravel, and silt

Ts Oligocene-Miocene shale, sandstone, siltstone, conglomerate, coal, ash

p€r Precambrian (Belt) argillite, quartzite, and limestone

Prepared by
Arthur L. Geldon
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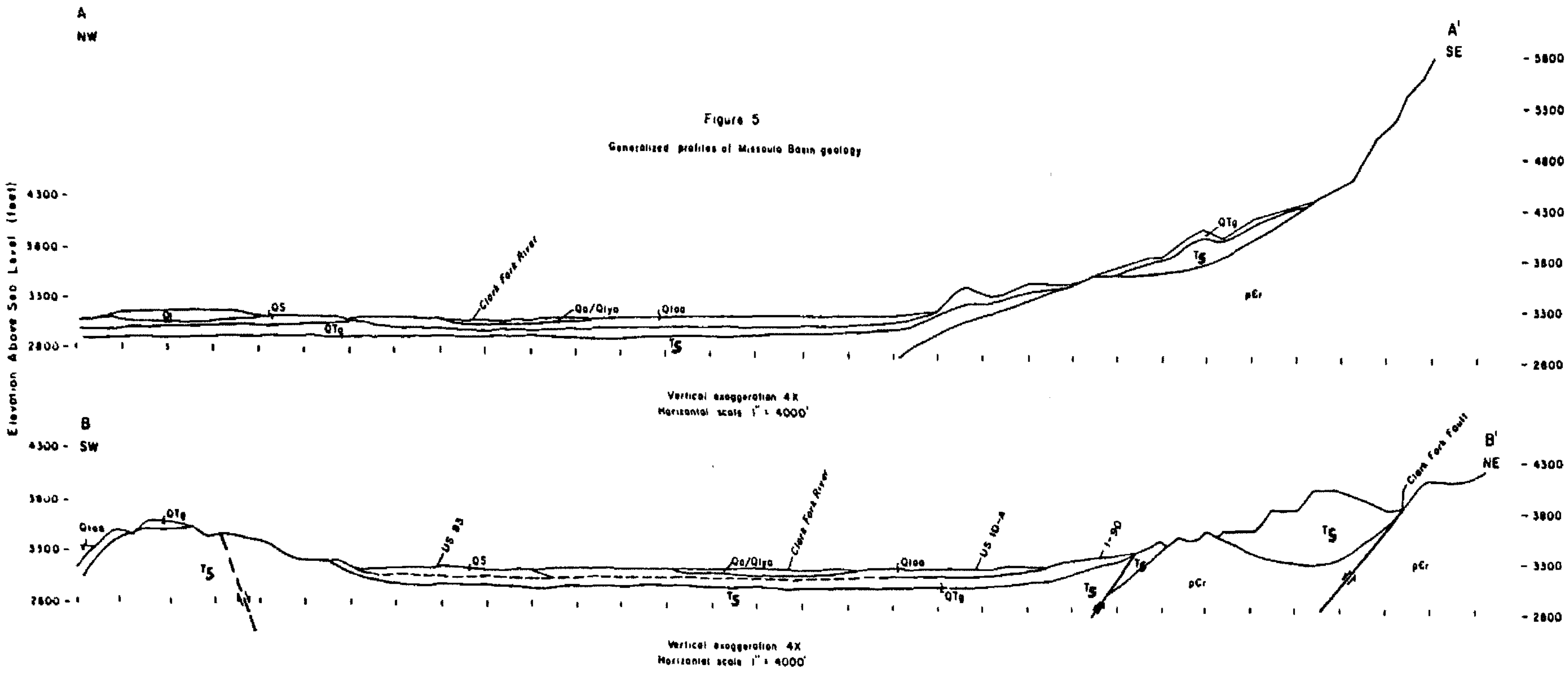
Drafting-John Cuplin

Figure 5

Generalized profiles of Missoula Basin geology



EXPLANATION

Qa	Holocene floodplain alluvium	Qs	Pleistocene pre-Lake Missoula sediments
Qtya	Pleistocene-Holocene terrace alluvium	QTg	Pliocene-Pleistocene bench gravels
Qtoa	Pleistocene terrace and flood alluvium	Ts	Oligocene-Miocene sediments
Ql	Pleistocene Lake Missoula sediments	PCr	Precambrian Belt Supergroup

rocks (Hall, 1969).

Cambrian Rocks

Hall (1969) and Nelson and Dobell (1961) mapped Cambrian rocks in the mountains bordering the Missoula Valley. Within the study area, Cambrian rocks crop out in the upper Rattlesnake Creek drainage. Because of their limited occurrence, they are not delineated on the geologic map of the basin (Plate 1). Hall (1969) correlated the rocks with exposures in the Philipsburg area and adopted the nomenclature of that area.

The Cambrian section around the Missoula Valley is approximately 2,800 feet thick and includes in ascending order the Silver Hill Formation (465 feet), the Hasmark Formation (1,860 feet), the Red Lion Formation (373 feet) and an unnamed dolomite unit (100 feet). The Silver Hill Formation consists of interbedded green shale and greenish gray glauconitic sandstone overlain by gray limestone with shale interbeds. The Hasmark Formation consists almost entirely of gray and grayish-orange dolomite. The Red Lion Formation consists of gray silty dolomite and dolomitic siltstone with greenish shale interbeds, which are overlain by gray laminated limestone and siltstone.

Table 2 Missoula Basin Stratigraphy

	Age	Formation	Map symbol	Maximum thickness (feet)	Area in basin (acres)	Description
Quaternary	Holocene	Active alluvium	Qa	20	4,535	Silt, sand, gravel, and cobbles in floodplains of Bitterroot and Clark Fork Rivers and Rattlesnake Creek
	Holocene	Fan alluvium	QF	80	588	Clay, silt, sand, gravel, and cobbles
	Pleistocene	Landslide alluvium	QlS	500	1,264	Clay, sand, and gravel derived from Tertiary and Pleistocene sediments
		Younger terrace alluvium	Qtya	40	4,344	Yellow Brown to beige silt, sand, and gravel underlying lower terraces along Bitterroot and Clark Fork Rivers and Rattlesnake Creek
	Pleistocene	Older terrace alluvium	Qtoa	90	12,593	Yellow brown, pink and beige silt, sand, clay, and gravel (Qs) capped with brown gravel; forms upper terraces along Clark Fork and Bitterroot Rivers and tributary creeks
		Lake Missoula sediments	Ql	115	2,016	Varved pink clay and beige silt with yellowish sand interbeds
		Glacial till	Qt	unknown	68*	Clay, silt, sand, gravel, cobbles, boulders (unsorted)

Table 2 Missoula Basin Stratigraphy (continued)

	Pleistocene	Bench gravels	QTg	245	8,056	Tan, brown, red brown, and orange cobbly gravel, silty gravel, silt, and sand unconformably overlying Renova Fm. and Precambrian rocks on benches flanking basin
Tertiary	Pliocene					
Tertiary	Miocene Oligocene	Renova equivalent	Ts	2,500	3,113	Partially to fully consolidated, variegated claystone, silt stone, sandstone, conglomerate, and lignite
Paleozoic	Cambrian	Unnamed				Dolomite
		Red Lion Fm		2,800	Mapped with Belt Series	Gray Silty dolomite and dolomitic Siltstone overlain by laminated gray limestone and silt stone
		Hasmark Fm				Gray dolomite
		Silver Hill Fm				Green Shale and glauconitic sandstone overlain by gray limestone and shale
Precambrian	Upper Precambrian (0.8 to 1.6 billion years B.P.)	Belt Supergroup: Missoula Group	PЄr	16,000	80,183	Red, purple, pink, and green sandy argillite, siltite, argillaceous quartzite, and quartzite
		Belt Supergroup: Wallace Formation		9,000		Greenish gray and gray limy-argillite, impure limestone, siltite, and quartzite

*Some till included in area mapped as PЄr

Oligocene-Miocene Sediments

Middle Tertiary sediments, correlative on the basis of similar lithology and stratigraphic position with the Renova Formation of the Jefferson Basin (Kuenzi and Fields, 1971), overlie the Precambrian and Cambrian rocks with considerable unconformity. These sediments crop out in the foothills on the north and southeast sides of the basin and at Council Hill; they are also encountered in drilling beneath Holocene-Pliocene alluvium within the Missoula Basin and the Butler Creek drainage. McMurtrey and others (1965) mapped these deposits as "Tertiary older alluvium", and Hall (1969) included them in his "Tertiary basin deposits" unit. In uranium exploration drill holes within and adjacent to the Missoula Basin, these middle Tertiary strata are 2,000 to 2,500 feet thick (written communication, Bendix exploration geologist, 1978). According to McMurtrey and others (1965) these sediments were deposited in marshy lowlands periodically fed by volcanic ash eruptions and alluvial fans.

The exact age of the sediments is unknown because datable vertebrate fossils have not been found within them. According to McMurtrey and others (1965), several geologists have assigned to them an Oligocene age on the basis of tenuously datable fossil flora. However, Kuenzi and Fields (1971) consider the genetically and stratigraphically equivalent Renova Formation of the Jefferson Basin to be Oligocene-Miocene in age. Middle Tertiary sediments in the

Missoula Basin are probably Oligocene - Miocene also. Four distinct facies are present.

The Miller Creek facies is well-exposed in borrow pits between Upper and Lower Miller Creek Roads and at the mouth of the Butler Creek valley. This unit consists of brown, green and white micaceous sandstone and conglomerate. Grains and clasts within these rocks are rounded, generally less than 4 inches in diameter, and consist of fragments of Belt rock, and subordinate igneous and metamorphic rock types. The unit is unconsolidated to consolidated (locally containing calcite cement), cross-bedded, and water-bearing at depth. In a borrow pit by Lower Miller Creek Road, oxidized Plio - Pleistocene gravels overlie the faulted surface of Miller Creek facies sediments.

The South Hills facies is exposed from Upper Miller Creek Road to Moose Can Gully and on the east side of Butler Creek; it is also encountered in drill holes from the mouth of the Butler Creek Valley to the Missoula County Airport. This unit consists of gray, green, blue, yellow, and tan clay-stone with lenses of water-bearing sand and gravel, as typified by Oligocene-Miocene strata encountered in Well MP-17 of Appendix I. In this well, as in many others, clayey strata of the South Hills facies overlie sandstone and conglomerate (sand and gravel) of the Miller Creek facies.

The Lincoln Hills facies crops out from Moose Can Gully to Pattee Canyon and in the Lincoln Hills of the Rattlesnake

Creek drainage. It consists of lavender, gray, red, and tan claystone, gravelly clay, and clayey breccia with interbedded lignite and thin seams of water-bearing gravel. It is typified by Tertiary strata in the Runke Well log of Appendix I.

The North Hills facies is exposed in between Grant and Rattlesnake Creeks and is encountered in drill holes on the north side of Missoula. It consists of orange to white sandstone and purple shale with subordinate lignite.

Bench Gravels

Precambrian and middle Tertiary rocks are unconformably overlain by unconsolidated, predominantly coarse-grained alluvium in the basin foothills, at Council Hill, and in Pattee Canyon. These deposits extend beneath terrace and flood plain alluvium on the valley floor, where they are distinguishable from them by their greater proportion of silt and clay. Within the basin, the lower alluvial unit is as much as 245 feet thick; in the foothills, it is absent on upper slopes and as much as 20 feet thick along the edge of the valley.

The unit consists predominantly of gravel and cobbles in a matrix of sand, silty sand, or clayey sand with seams, pockets, and discontinuous layers of sand, gravelly sand, silt, and clay. Coarser layers are water bearing beneath the valley floor. The sediments are predominantly oxidized to shades of brown, red-brown, and orange, although upper layers are gray and unoxidized. The texture varies from compact to open where the unit is exposed in cuts. Cross-bedding was observed in a borrow pit near the head of Moose Can Gully. The unit is represented in Appendix I in the logs of Wells MP-29 and MP-17 and the Wheeler well.

The alluvium is assumed to be Pliocene to Pleistocene in age because of its stratigraphic position between the Oligocene-Miocene sediments and the Pleistocene Lake Missoula sediments. Its lower part is lithologically similar to the Pliocene Sixmile Creek Formation of the Jefferson Basin (Kuenzi and Fields, 1971). Its upper part, however, is probably Pleistocene in age because it is fresher, and less compact than the lower part and contains thin silt beds which resemble Lake Missoula sediments.

By analogy with modern desert basins of the Southwestern United States, it is suggested that the Bench Gravel unit originated as bajadas and basin fill in a closed basin, bordered by actively rising mountains during the Pliocene epoch. With increasing climatic humidity during early Pleistocene times, the Clark Fork and Bitterroot Rivers began eroding through these deposits. The onset of glacial activity resulted in the deposition of outwash, flood debris, and small backwater lake or pond sediments within the basin, all of which make up the upper layers of this unit.

Lake Missoula Sediments

Sediments of Glacial Lake Missoula crop out on the southern edge of the basin, along the flanks of Blue Mountain and the South Hills, and on the northwest side of the basin, from the boundary ridge to the junction of Interstate 90 and U.S. 93. Presumably, they were more extensive within the basin during Pleistocene time but were eroded by outburst floods which periodically drained Glacial Lake Missoula.

The lake beds consist predominantly of varved pink clay and beige silt, which easily cleave along bedding planes. Along the southern edge of the basin, they contain layers of fine-grained yellowish sand. They are unfossiliferous, but McMurtrey and others (1965) report fossil tracks of several arthropod and annelid species. The lake beds are as much as 115 feet thick on the northwestern side of the basin but generally less than 50 feet thick on the southern side.

Thin shoreline deposits of sand and gravel mantle wave-cut terraces in the hills flanking the basin at elevations ranging from 3,250 to 4,200 feet (McMurtrey and others, 1965). These beach deposits are well-exposed on the southwestern flank of Waterworks Hill, but in most places, they are vaguely defined by aligned vegetation.

The Lake Missoula deposits correlate with several advances of the Cordilleran ice sheet into the Purcell Trench of Idaho (Alden, 1953). According to Curry and others (1977), these deposits represent at least 35 cycles of filling and draining spanning a time period of 875 to 1,500 years. Each cycle of filling lasted 25 to 60 years, and subsequent floods, caused by flotation and rupture of the ice dam, lasted no more than two weeks each. Evidence from a peat bog at Lost Trail Pass in the Bitterroot Mountains suggests that final glacial retreat from northwestern Montana occurred by 12,000 years ago (Mehringer and others, 1977).

Flood-plain and Terrace Alluvium

Although mapped separately, these units are lithologically similar and hydrologically integrated. They are best exposed along the edge of stream terraces and in borrow pits flanking the access road to the City Dump. The log of Well MP-29 in Appendix I contains a description of the older terrace alluvium. The flood plain alluvium is as much as 20 feet thick; the younger and older terrace alluvium are as much as 40 and 90 feet thick, respectively.

The alluvial deposits consist of water-bearing brown, beige, and pink silt, sand, and gravel, which are typically well-sorted within individual layers. The older terrace alluvium is capped with a layer of brown cobbly gravel, which thins westward from the east side of the basin. This gravel appears to have been deposited by outburst floods sweeping through the Pattee Creek, Rattlesnake Creek and upper Clark Fork drainages in response to periodic draining of Glacial

Lake Missoula. Gravel bars of flood origin overlie Oligocene-Miocene sediments in the Lincoln Hills and South Hills (these gravel bars are not shown on Plate I where they are too small for the map scale).

The older terrace alluvium, because of its origin, must be Pleistocene in age. The flood-plain alluvium is clearly Holocene. The younger terrace alluvium is Pleistocene or Holocene in age and is probably related to neoglacial events of the last 4,000 years.

Other Quaternary Alluvium

Pleistocene alpine glacial till, consisting of unsorted clay to boulder-sized material,has been mapped and described by Vander Poel (1979) in the upper Rattlesnake Creek drainage. Composite alluvial fans, ranging in age from Pleistocene to Holocene, occur at the mouths of many gullies and intermittent streams around the flanks of the basin; sediments within them resemble those of the Bench Gravel unit. Large landslides, probably Pleistocene in age and predominantly involving Oligocene-Miocene sediments, are mapped in the north foothills. They are distinguished by hummocky terrain, sag ponds, and disturbed bedding. Their alignment along the trace of the Clark Fork Fault, a structure recurringly active from Precambrian to Pleistocene time (Hall, 1969), suggests that they may have been caused by seismic activity or groundwater seepage along this fault.

Structure

The north side of the valley is downdropped along the northwest trending Clark Fork Fault, a steeply dipping normal fault extending 150 miles from Coeur d' Alene, Idaho to the vicinity of Helena, Montana. Segments of this fault are reported to show right-lateral movement, although Hall (1969) observed no such movement in the Missoula Basin. Movement along the fault has occurred repeatedly from Precambrian through possibly Pleistocene time, (McMurtrey and others, 1965), and Hall calculates 6,500 feet of throw on the structure. Parallel faults cutting the north hills along its south-facing front, (McMurtrey and others, 1965) the South Hills near the Miller Creek divide (Plate 1), and the north side of the Bitterroot Range (Hall, 1969) are probably related in origin.

The east side of the basin may be downdropped along a steeply dipping fault at the base of Mounts Sentinel and Jumbo (McMurtrey and others, 1965). Fault gouge is reported by McMurtrey and others in a well along this structure. Although Nelson and Dobell (1961) do not show such a fault on their map of the east side of the basin, the topography of Mount Sentinel suggests that its west face is an exhumed fault scarp.

Parallel arcuate thrust faults bordering the north side of the Idaho Batholith form the southwest wall of the basin (Hall, 1969). Sub-parallel faults are mapped by Nelson and Dobell (1961) in the Rattlesnake Creek drainage. All of these faults are overthrust from the southwest and may have developed in response to emplacement of the Idaho Batholith during the Tertiary period. Hall (1969), however, attributes a possible Cretaceous age to the thrusting.

North-northwest trending faults cut McCauley Butte, Water-Works Hill, and the north flank of Blue Mountain (Hall, 1969). Other faults of similar trend undoubtedly are buried beneath the valley fill. Hall suggests a post-thrusting age for these structures.

HYDROLOGY

Groundwater

Description of Aquifers

There are three sources of groundwater within the Missoula Basin. Pliocene, Pleistocene, and Holocene sand and gravel beneath the valley floor yield large quantities of water to wells. However, in the foothills, where this alluvium is above the water table, it does not furnish water. Small quantities of water are available from confined sand and gravel layers within the Oligocene-Miocene sediments and from fractured Precambrian bedrock. The distribution of aquifers is shown on Plate 2.

Pliocene-Holocene Alluvium (Qtua) - This aquifer, which includes Bench gravels and terrace, flood plain, and fan alluvium, contains discontinuous layers of varying permeability. The coarser sand and gravel layers readily yield water to wells, but flow is small to non-existant with increasing amounts of finer particles in the alluvium. Permeable layers connect at depth as less permeable ones taper out. The average thickness of the unit is 151 feet; it is 243 feet thick near the mouth of Grant Creek and 98-137 feet thick in wells along the eastern and southern margins of the valley (Plate 2).

The aquifer is generally unconfined. It is recharged, as a whole, by precipitation, irrigation, and hillside runoff at the surface and by underground seepage from Tertiary and Pleistocene sediments exposed in the foothills. Water flows into the aquifer from the Clark Fork and Bitterroot Rivers and sidestreams entering the valley (McMurtrey and others, 1965). Beneath Pleistocene lake beds on the northwest side of the basin, the aquifer is recharged mainly by seepage from unconfined strata.

Water discharges from the aquifer by seepage beneath the lakebeds, subsequently flowing into the Clark Fork downstream from the basin (Grimestad, 1977). Large quantities of water are pumped for agricultural, commercial, and residential use. Phreatophytic plants cause some loss by evapotranspiration.

Oligocene-Miocene Sediments (Ts) - Discontinuous layers of sand and gravel, commonly less than 10 feet thick, transmit 1-20 GPM (gallons per minute) of water under pressures maintained by confinement between impermeable clay layers. The sporadic occurrence of these water bearing horizons makes it impossible to predict the depth at which they will be encountered in wells. As seen on Plate 2, water bearing layers in the South Hills occur from 19-274 feet below the surface.

Because the confining clay layers prevent downward percolation of precipitation, the water table may be several hundred feet deep beneath exposed Oligocene-Miocene sediments. Sand and gravel layers beneath the water table yield water to wells, even though they may not extend to the surface where outcropping sand and gravel layers are recharged by precipitation. The Oligocene-Miocene sediments are also recharged by leakage from the overlying Pliocene-Holocene aquifer beneath the valley floor.

Water loss from the aquifer in the foothills occurs by seepage downslope to sidestreams and valley floor alluvium and by pumpage for residential and commercial use.

Precambrian rock (p€r) - The bedrock contains small quantities of water within fractures and at the base of the overlying colluvial soil mantle. The rock, itself is relatively impermeable to water flow. Flows to wells from fracture zones in the rock are generally less than 1 GPM. Water-bearing fracture systems vary from 4 to 714 feet thick and occur sporadically at depths ranging from 38 to 654 feet below the surface (Plate 2).

Fractures extending to the ground surface or soil mantle transmit surface water and precipitation downward, recharging the water-bearing zones. Water discharges from fracture zones by residential pumpage and from the soil mantle by seepage downslope to streams and other stratigraphic units.

Hydrologic Properties

The quantity of water that soil or rock will yield to wells depends on the volume, shape, and size of interconnected pores. Finer materials, like silt and clay, have greater pore space (porosity) than coarser materials like sand and gravel, but the larger size of interconnected pores in the sand and gravel allows them to transmit water more readily when saturated. In this study, the porosity of sand and gravel was assumed to be 40 percent, which, as noted in McMurtrey and others (1965), is an average value for those materials.

In an unconfined aquifer, the water taken into or released from storage occurs mainly as a result of gravity drainage and filling of pores; this property, known as the specific yield, equals the porosity minus the ratio of water held by matric suction (specific retention). In a confined aquifer, changes in storage result from expansion and contraction of the water and matrix material as a result of changes in head. This property, the storage coefficient, also equals the porosity minus the specific retention. Average specific yields range from 0.1 to 0.35; average storage coefficients range from 10^{-2} to 10^{-5} (Theis, 1963). Confined aquifers yield less water than unconfined aquifers because of their restricted recharge. All other things being equal, clay and silt yield far less water than sand and gravel because the surface tension increases as the grain size decreases. For a specific unconfined aquifer in the Missoula Basin, Grimestad (1977) noted that the specific yield also varies with the length of time the aquifer is pumped.

Coefficients of storage and specific yields were estimated for aquifers within the basin using the above relationships. Unconfined Pliocene-Holocene alluvium, in individual pump tests was assigned time-dependant specific yields ranging from 0.11 to 0.35, assuming a maximum value of 0.35. Pliocene-Holocene alluvium confined between Pleistocene lake beds and Oligocene-Miocene sediments was assigned a storage coefficient of 10^{-2} because of restricted recharge. The Oligocene-Miocene and Precambrian aquifers were assigned storage coefficients of 10^{-4} and 10^{-5}, respectively, because of increasingly restricted recharge and permeability.

The infiltration rate is a measure of a material's ability to transmit water downward from the ground surface. Infiltration rates used in this study were estimated from percolation tests conducted by the U.S. Soil Conservation Service, U.S. Forest Service, and Stensatter, Druyvestein, and Associates. Infiltration rates through Pliocene-Holocene alluvium commonly range from 1.5 to 6 inches per hour (Table 3). Infiltration rates for the Oligocene-Miocene, as a whole, range from 0.2 to 0.4 inches per hour, although movement through saturated sand and gravel is more rapid. Infiltration rates through colluvial soils derived from Precambrian bedrock commonly range from 0.6 to 6 inches per hour, although downward movement through fractures in the rock is very much slower.

Table 3: Hydrologic Properties of Missoula Basin Stratigraphic Units

Stratigraphic Unit	Soils	Hydrologic Unit	Average Thickness (ft)	Infiltration Rate[3] (inches/hr) USFS	SCS	S/D	Hydraulic Conductivity[4] (inches/hr)	Transmissivity (GPD/ft)	Specific Capacity[4] (GPM/ft)
Active Alluvium	Alluvial land, Tacum Grantsdale			1.-3	3				
Fan Alluvium	Grantsdale, Perma				2-6				
Glacial Till	—								
Younger Terrace alluvium	Quigley, Tally, Tacum, Grantsdale	(QTua)	151'	1.5-5	1.5-3		340 (average 19 pump tests Range: 0.65-2631	699,927	430 (average 19 tests) Range: 3-3000
Older Terrace flood alluvium	Grantsdale, Quigley				1.5-3	1.4			
Bench gravels	Perma			5-10	2-6	5			
Landslide	Round Butte	—	—		0.3		—	—	—
Lacustrine Sediments	Round Butte	—	65'		0.3	0.2	—	—	—
Olig.-Mioc. Sand & Gravels	Round Butte	(Tr)	—		0.3	0.4	11.3(average 6 tests) Range: 0.95-34.9	979	0.514(average tests) Range: 0.026-2.00
Fractured Belt Rocks	Winkler-Sharrott Association, Holloway	(P€r)	—	1.5-5[5]	0.6-6[5]		1.39(average 6 tests) Range: 0.003-3.73	210	0.106 (average 6 tests) Range 0.014-0.218

[1] Average of 38 wells, Qs sub-unit (Silt, clay, sand, gravel) averages 91 feet in 14 wells
[2] Average of 10 wells
[3] USFS - data from Forest Service; SCS - data from Soil Conservation Service, S/D - data from Stensatter, Druyvestein and Associates
[4] Calculated from well log data, using Jacob (1963a, 1963b); Applies only to sand & gravel
[5] Applies to Colluvial Soils only

The specific capacity, which is determined by pumping a well at a constant rate for a measured time, is the ratio of the pumping discharge to the drawdown of the water table in the well. The specific capacity and other hydrologic properties were calculated as shown in Appendix II, according to methods described in Jacob (1963a, 1963b). The specific capacity of Pliocene-Holocene alluvium in 19 tests ranged from 3 to 3,000 gallons per minute per foot of drawdown (GPM/ft), averaging 430 GPM/ft (Table 3). The specific capacities of Oligocene-Miocene sand and gravel layers and fractured Precambrian rock are much lower, averaging 0.514 GPM/ft and 0.106 GPM/ft respectively.

The hydraulic conductivity (permeability) is a measure of horizontal flow capacity through an aquifer. Transmissivity relates the hydraulic conductivity to the thickness of the aquifer. These properties were calculated from pump test data, as shown in Appendix II. The hydraulic conductivity and transmissivity of the Pliocene-Holocene alluvium average 339.9 inches per hour and 699,927 gallons per day per foot (GPD/ft), respectively (Table 3). A comparison between hydraulic conductivities calculated in this and other studies for the aquifer is shown in Table 4.

Table 4: Comparison of average hydraulic conductivities calculated for Quaternary - Tertiary Alluvium.

Report	Hydraulic Conductivity (in/hr)
Geldon (this report)	340
McMurtrey and others (1965)	
Calculated from specific capacity	182
Calculated from pump test observation well drawdowns	599
Botz (1969), calculated from specific capacity	1,007
Grimestad (1977), calculated from observation well drawdowns	
Surface sand and gravel	685
Intermediate sand, silt, clay, gravel	10
Lower sand, gravel and silt	270

The hydraulic conductivity and transmissivity of Oligocene-Miocene sand and gravel in 6 tests average 11.3 inches per hour and 979 gallons per day per foot, respectively. These properties, for the Precambrian aquifer in 6 tests, average 1.39 inches per hour and 210 gallons per day per foot, respectively.

Hydrologic properties calculated for individual wells are listed in Appendix III.

Water Quality and Age

Circulation through the Pliocene-Holocene aquifer is relatively rapid, whereas in the Oligocene-Miocene and Precambrian aquifers, it is very slow. Konizeski and Alt (1972) determined the minimum ages of groundwater in the Missoula Basin using the ratio of dissolved Carbon^{14} to Carbon^{12} in well water. Water in storage in the upper aquifer generally gives an "age" of 25 to 740 years with increasing distance away from stream recharge areas. Areas where circulation is restricted or groundwater has been pumped heavily for prolonger periods yield water up to 2,130 years in "age". Renova Formation sediments within the basin commonly yield water greater than 2,000 years in "age" and locally, up to 6,420 years in "age". Precambrian rock yields water 1,670 to 2,030 years in "age". All of these "ages" are considered to be minima because the water sampled is most likely a mixture of older and younger groundwater.

Ground water quality within the basin was studied by Juday and Keller (1979). The water quality is generally well within Environmental Protection Agency standards for drinking water (Table 5). Aquifers with slow circulation, on average, have higher concentrations of dissolved solids because the water has a longer time to chemically weather the solid constituents of the aquifer. Dissolved solids contained in groundwater from all aquifers are generally less than 500 ppm (parts per million). The pH ranges from 6.8 to 8.5 (neutral to slightly alkaline), with generally increasing values from northeast to southwest. Individual aquifers are indistinguishable on the basis of pH.

Groundwater, in general, is moderately hard, although Pliocene-Holocene alluvium on the north side of the basin

Table 5: Average concentrations of common constituents in Missoula Basin Aquifers[1]

	EPA Standards for Drinking Water	Pliocene-Holocene Alluvium: Clark Fork Basin	Pliocene-Holocene Alluvium, Missoula Basin: Hellgate Valley (6 wells)	Main Urban Area (19 wells)	Airport Area (3 wells)	Grant Creek Area (2 wells)	Target Range (10 wells)	Rattle-snake Creek (1 well)	Miller Creek (1 well)	Oligocene-Miocene: Clark Fork Basin	Oligocene-Miocene: Msla. Basin (5 wells)	Precambrian Rock: Msla Basin
Calcium (Ca)	75	38	36.7	37.3	25.0	9.6	40.7	23.0	20.4	33	19.3	18.1
Magnesium (Mg)	30	14	15.6	20.3	11.4	7.3	16.7	10.8	8.5	11	13.3	22.8[9]
Sodium (Na)	--	8.5	8.2	7.6	7.3	2.8	8.2	3.6	4.5	56	13.8	8.5
Silica (SiO_2)	--	15	12.3	15.9	17.0	8.7	15.3	10.8	20.7	32	30.2	15.0
Nitrate (NO_3)	45	3.8	0.72	0.09	0.75	0.039	0.78	0.14	2.1	23	0.58	0.042
Phosphate (PO_4)	--	--	0.020	0.018	0.032	0.019	0.025	0.014	0.031	--	0.034	0.002
Sulfate (SO_4)	200	7.7	9.0[4]	28.5	8.0	3.5	27.7[6]	4.0	5.3	14	8.9[7]	16.1
Chloride (Cl)	200	2.5	5.8[5]	4.5	1.9	1.0	5.0	1.1	2.2	8.4	2.2	1.4
Bicarbonate (HCO_3)	--	140	181	198	140	59	195	131	102	210	144	171
Dissolved solids	500	165	274	314	219	91	306	186	187	292	241	255
Turbidity (NTU)	1		0.26	0.26	0.34	0.38	0.24	-	1.56	-	0.56[8]	0.72
pH	--	7.0	7.7	7.7	7.7	7.0	7.7	7.8	7.1	8.1	7.6	7.8
Iron (Fe)	0.3	0.33	--	--	--	--	--	--	--	2.3	--	--
Fluoride (F)	--	0.1	--	--	--	--	--	--	--	0.4	--	--
Potassium (K)	--	2.5	2.4	2.0	1.7	0.9	2.5	2.2	2.7	8.3	2.1	1.1
Manganese (Mn)	0.5	--	--	--	--	--	--	--	--	0.42	--	--

1. Data from Juday and Keller (this study) except as noted.
2. Data from U. S. Environmental Protection Agency (1976).
3. Data from Boettcher and Gosling (1977).
4. Average of 4 wells; 16 ppm if 2 wells near sewage plant with high sulfate are included
5. Average of 5 wells; 15.6 ppm Chloride in 6th well.
6. Average of 9 wells.
7. Average of 4 wells; 38.4 ppm in 5th well.
8. Average of 4 wells; 60.8 NTU in 5th well due to 5 ppm Fe.
9. Range 5.3 - 46.4 ppm.

and in the drainages of Grant Creek, Butler Creek, and Rattlesnake Creek ranges from soft to moderately hard. Hardness values, expressed as the sum of magnesium and calcium ion concentrations, range on average from 50 to 82 ppm through most of the basin in groundwater from the Pliocene-Holocene alluvium. The higher values are, concentrated in the area between McCauley Butte and Council Hill, corresponding to locally increased pH. Groundwater from the Oligocene-Miocene and Precambrian aquifers, on average, contains slightly less calcium than that from the Pliocene-Holocene alluvium. Magnesium locally exceeds EPA standards in water from the Precambrian rocks, probably because of equilibration with strata containing magnesium silicates or dolomite.

In general, the water can be classified as calcium or calcium-magnesium bicarbonate with regard to major cations and anions. Sulfate concentrations are usually less than 40 ppm; chloride concentrations are usually less than 20 ppm; both are well within EPA standards. Measured bicarbonate concentrations commonly are in the range from 150 to 200 ppm.

The ratio of calcium to silica can be used as an index of freedom of groundwater circulation because silica has low solubility in cool groundwater and accumulates where circulation is restricted. Calcium/silica ratios decrease from an average of 2.3 in water from unconfined Pliocene-Holocene alluvium to 0.64 in water from the confined Oligocene-Miocene sediments. Within the Pliocene-Holocene alluvium, the importance of the Clark Fork in recharging this aquifer is reflected in decreasing calcium/silica ratios away from it. From the Mullan Road area to the vicinity of the airport, these ratios decrease from 2.98 to 1.47.

Iron concentrations greatly exceed EPA standards in water from the Oligocene-Miocene and Precambrian aquifers, locally being 16 to 23 times higher than the acceptable value of 0.3 ppm (Juday and Keller, 1979; McMurtrey and others, 1965). Iron concentrations in water from the Pliocene-Holocene alluvium are slightly higher, on average, than EPA standards. Although it discolors the water and gives it a bad taste, the iron is not harmful to humans at the concentrations present.

Many of the differences found by Boettcher and Gosling (1977) between Pliocene-Holocene and Oligocene-Miocene aquifer water in the Clark Fork Basin were not observed in the Missoula Basin. Silica, sodium, and turbidity are higher in water from the older unit, but no significant differences were observed in potassium, sulfate, chloride, nitrate, phosphate, bicarbonate, pH, and dissolved solids.

Water Table

The water table is the upper surface of the zone of saturation within an unconfined aquifer. In the Missoula Basin it fluctuates both seasonally and from year to year because of differences in precipitation, stream runoff, and water consumption.

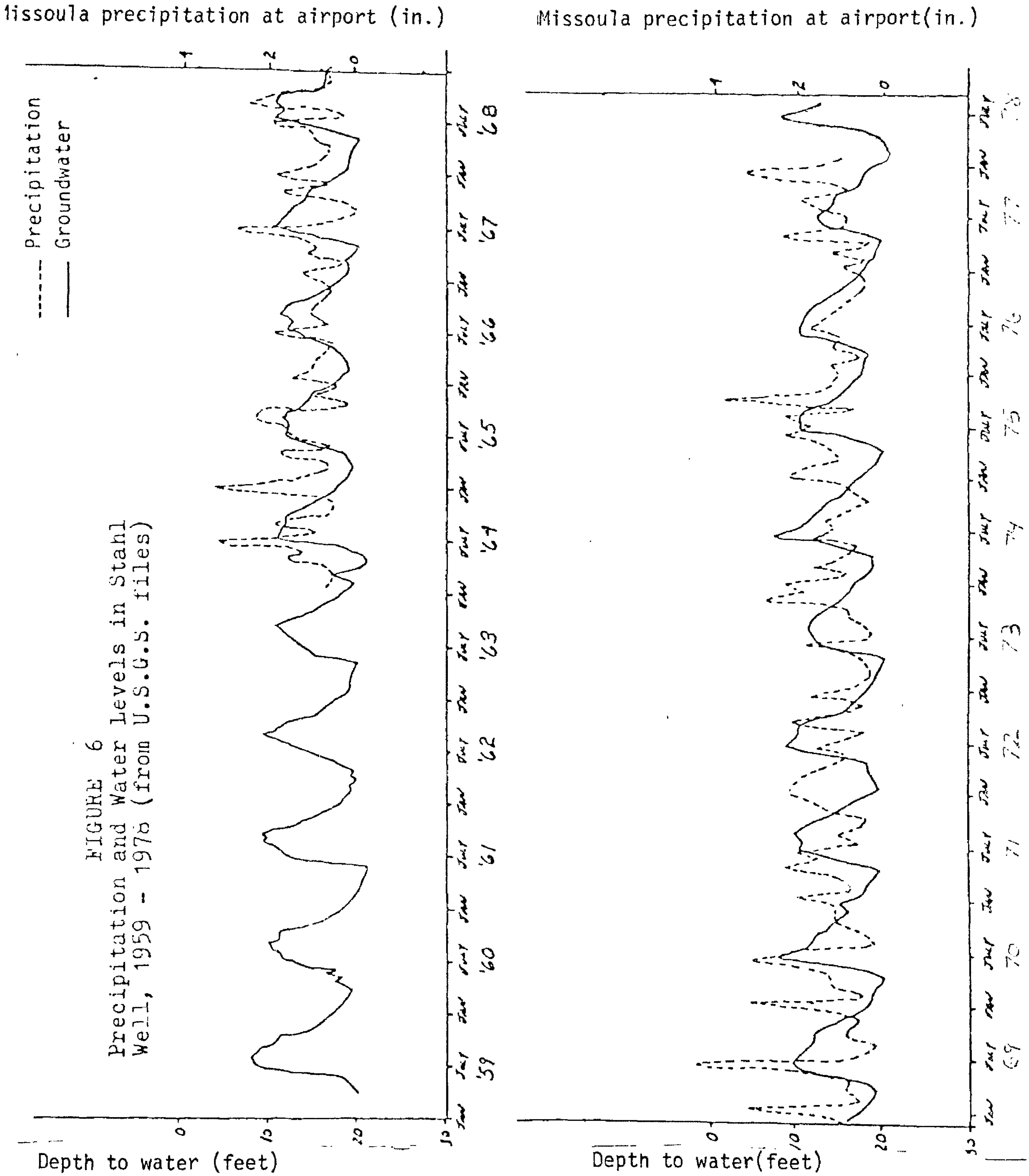


FIGURE 6
Precipitation and Water Levels in Stahl Well, 1959 - 1978 (from U.S.G.S. files)

Annual peak groundwater levels in an unpumped U.S. Geological Survey observation well, recorded over a 19 year period from 1959 to 1978 (Figure 6), were analyzed to establish recurrence intervals of low groundwater years. This well, which is located in T13N, R20W, S14, draws water from Pleistocene alluvium. Water in a nearby well has a C^{14} age of <50 years B.P. (Konizeski and Alt, 1972), implying that circulation is unrestricted in the area. Water levels in the well during the 1977-78 study year fluctuated in accord with other wells in the basin. Thus, one can assume that groundwater conditions in this well are fairly representative of the Pliocene-Holocene alluvium filling the basin.

Water levels in the observation well were most often at their maximum elevation during the first half of June and at their minimum elevation during the first half of April. On average, the peaks and troughs are separated by 3.5 months and are 10 feet apart in elevation. The lowest water levels are consistently around 20 feet deep from year to year, but groundwater peaks, as determined by Log Pearson III analysis, vary within a 100 year period from 7.6 to 13.7 feet below ground. The mean annual groundwater maximum is 10.4 feet. In 1977-78, the maximum was about 8 feet; in 1976-77, it was 13.25 feet. An apparent 6 to 8 year cyclicty in groundwater levels, indicated by drawing a smooth line through the peaks in the 19 year record, suggests that 1976-77 may have been the low point in one cycle and 1977-78 the beginning of a 5-7 year rise in groundwater levels. The lack of correspondence between precipitation and groundwater curves plotted in Figure 6 confirms that groundwater fluctuations are influenced by other factors than precipitation alone.

During 1977-78, groundwater levels in the basin were highest in the first half of July and lowest around March 1 (Appendix IV). Plates 3 and 4 are maps of the water table at its highest and lowest times of the year. Highest and lowest elevations and seasonal fluctuations of groundwater in observation wells are listed in Table 6.

The data indicate that groundwater in the basin during a better than average groundwater year (1977-1978) was never greater than 96 feet below the surface, averaging 39 feet deep. Groundwater near the Clark Fork and Bitterroot Rivers was never greater than 20 feet deep. A groundwater low centered beneath the airport, where minimum water levels in observation wells were generally in excess of 70 feet deep, may be caused by the impermeable nature of the Pleistocene lakebeds at the surface there. More likely it may result from groundwater depletion during the irrigation season. (See Chapter 5). During the study year, seasonal fluctuation in groundwater levels varied from 5 to 44 feet, averaging 8.4 feet in the main part of the basin (Table 6). Groundwater fluctuation near the Clark Fork and Bitterroot Rivers averaged 6 feet and varied directly with the river stage.

Table 6: Water Table Elevations
October, 1977 - September, 1978

Well	Location T,R,S,1/4	Highest Water Table Month	Highest Water Table Elevation	Lowest Water Table Month	Lowest Water Table Elevation	Difference (ft)
		Miller Creek				
Dahlberg	12N-20W-13C	July 15	3306	March 1	3294	12
Maloney	12N-20W-14b	July 15	3161	March 1	3144	17
		Hayes Creek				
Smith	12N-20W-10a	July 15	3148	March 1	3140	8
		Rattlesnake Creek				
MP-13	13N-19W-14b	July 15	3352	March 1	3330	22
		Butler Creek				
Hansen	14N-20W-26a	July 15	3311	Dec. 15	3275	36
MP-28	14N-20W-26c	July 15	3169	March 1	3155	14
		Airport area				
USFS	14N-20W-35c	July 15	3132	March 1	3120	12
Clay	13N-20W-15a	July 15	3117	March 1	3112	5
		Grant Creek				
Wheeler	13N-19W-6d	July 15	3158	March 1	3114	44
		Hellgate Valley				
Reely Bros.	13N-19W-8c	July 15	3151	March 1	3140	11
MP-19	13N-19W-17c	July 15	3146	March 1	3137	9
Edwards	13N-19W-18a	July 1	3140	March 1	3130	10
McCulloch	13N-19W-18d	July 15	3144	March 1	3134	10
Stahl	13N-20W-14a	July 15	3136	March 1	3122	14
		Cold Springs-Linda Vista				
Stobie	12N-20W-12b	March 1	3132	Dec. 15	3126	
		July 15	3132	Apr. 30	3126	6
MP-29	12N-20W-1a	July 1	3125	March 1	3120	5
		MaClay Bridge				
Hauser	13N-20W-26c	July 15	3103	March 1	3097	6
Kallis	13N-20W-35b	July 15	3107	March 1	3100	7
		Target Range				
Monaco	13N-20W-24c	July 15	3123	March 1	3117	6
State Forest North.	13N-19W-30b	July 15	3132	March 1	3126	6
MP-27	13N-19W-30a	July 15	3136	March 1	3129	7
		Wapkiya				
MP-14	13N-19W-32d	July 15	3137	March 1	3129	8
MP-24	13N-19W-33d	July 15	3148	March 1	3138	10
		Downtown Area				
MP-7	13N-19W-29d	July 15	3143	March 1	3133	10
MP-20	13N-19W-20d	July 15	3143	March 1	3136	7
MP-21	13N-19W-27c	July 15	3149	March 1	3141	8
MP-22	13N-19W-21c	July 15	3165	March 1	3156	9
MP-26	13N-19W-32a	July 15	3139	March 1	3131	8
MP-30	13N-19W-22c	July 15	3169	March 1	3160	9
MP-31	13N-19W-22c	July 15	3166	March 1	3159	7
MP-32	13N-19W-22c	July 15	3155	March 1	3146	9
MP-33	13N-19W-22c	July 15	3154	March 1	3144	10
MP-34	13N-19W-22d	July 15	3166	March 1	3156	10
		Bedrock				
Renz	14N-19W-21a	July 15	3780	March 1	3779	1
Wornath	12N-20W-2c	July 15	3149	March 1	3148	1

The Hellgate Valley experienced an average 10.8 feet of fluctuation, and the downtown area, an average 8.7 feet of fluctuation, probably reflecting better stream recharge in the latter area. An observation well at the base of the South Hills had an unusual double peak, possibly resulting from multiple periods of hillside runoff. The two bedrock wells that were monitored showed slightly more than 1 foot of seasonal variation. The greatest fluctuations occurred in wells within the tributary valleys, where seasonal variations of 12 to 44 feet were recorded. These sharp, pronounced peaks reflect the high runoff in those valleys during the late Spring months.

The net effect of the seasonal fluctuation is to shift the water table contours southwestward along the gradient of the water table as groundwater levels rise. This suggests that if groundwater reserves are being depleted by current use, one should see a northeastward shift in groundwater contours between maps drawn now and in the past, if they represent similar times in the seasonal and year-to-year cycles. A map prepared by McMurtrey and others (1965) shows the water table in the Missoula Basin in October, 1962, about 2 months past the peak in a groundwater year similar in supply to the present one. Groundwater levels in August 1962, at the peak, were about 2 feet higher than in October, as indicated from U.S.G.S. observation well records. This would shift the groundwater contours slightly southwestward at the peak placing those in the urban area in a position virtually identical to the one at the time of the peak in 1978. The lack of change in the configuration of the water table in the urban area from 1962 to 1978 implies that groundwater there is not being depleted by current usage.

Water Movement

Groundwater moves downslope perpendicular to the water table contours. Thus, as shown on Plates 3 and 4, movement in the Basin is predominantly southwestward towards the Clark Fork and Bitterroot Rivers. McMurtrey and others (1965) contend that the Clark Fork is influent from the Hellgate to its confluence with the Bitterroot and effluent downstream from there (i.e. within the basin, river water moves outwards into the groundwater system, eventually flowing back to the Clark Fork downstream from Kelly Island). Grimestad (1977) in studying the Hoerner - Waldorf well field confirmed that the Clark Fork is effluent in that vicinity. The present report indirectly confirms that the river is influent within the Missoula Basin because the river stage - correlative fluctuation of water levels in wells immediately adjacent to the river, and the circulation dependent decrease in calcium/silica ratios and increase in C^{14} ages away from the river all suggest that the Clark Fork circulates water to the valley fill as it flows through the basin.

Groundwater moves downslope very steeply in the foothills and tributary valleys and gently on the valley floor. Average gradients in Grant Creek, Rattlesnake Creek, and Butler Creek range from 100 to 150 feet per mile, whereas through the main part of the basin, the average gradient is about 15.3 feet per mile. On the northwestern edge of the Hellgate Valley, the gradient increases from 17.6 feet per mile in March to 33.4 feet per mile in July, as irrigation draws down groundwater reserves.

Discharge (volumetric flow in cubic feet per day) and velocity (average particle flow in feet per day) through sections of the basin can be calculated using the formulas:

$$1.\quad Q = TIW = KIA$$

$$2.\quad V = Q/pmw = Q/pA$$

where:

Q=	discharge	V=	Average velocity
T=	Transmissivity	p=	Porosity
I=	Gradient of Water table	m=	Thickness of section
W=	Width of flow section	K=	Hydraulic conductivity
		A=	Cross-sectional Area

The average discharge through the main part of the basin is about 5,142,052 ft^3/day and the velocity, about 6.2 ft/day, increasing as the water table drops and its gradient increases in response. The average discharge and velocity in other areas are listed below in Table 7.

Table 7 Groundwater movement through parts of Missoula Basin

	Discharge (ft^3/day)	Velocity (ft/day)
Urban area	5,142,052	6.2
Hellgate Valley (Mullan Road area)	1,813,478	4.3
Airport area	197,360	0.2
Grant Creek	219,565	1.6
Butler Creek	129,992	1.3
Rattlesnake Creek	170,069	1.1

Differences in discharge and velocity within the same aquifer result from local variations in composition, thickness, hydraulic conductivity, and water table gradient.

Groundwater flows out of the basin beneath the Pleistocene lake beds on the northwest side of the valley. The discharge in this area is 1,813,478 ft^3/day (Table 7), which annually amounts to 661,919,470 ft^3 or 15,195 acre-feet.

Storage

The volume of water in storage in the Pliocene-Holocene and Oligocene-Miocene aquifers is the product of their saturated volumes and porosities. McMurtrey and others (1965) estimated that the valley fill in the Missoula Valley as a whole has 30 million acre-feet of groundwater in storage, of which about 8 million acre-feet are available to wells. According to these authors, the upper 200 feet of material, equivalent to the Pliocene-Holocene alluvial aquifer, contains $1^3/4$ million acre-feet of available water. These estimates are probably too high because they ignore the lower permeability and yield of the Oligocene-Miocene sediments, which comprise the bulk of the valley fill. Even if the estimates were correct, the Missoula Basin would have much less than 8 million acre-feet of available groundwater because it forms but a small part of the entire Missoula Valley.

In the basin, the Pliocene-Holocene alluvium has an average thickness of 151 feet, depth to water of 39 feet, surface area of 22,643 acres, and porosity of 0.40. The amount of water in storage equals the saturated volume (22,643 ft x(151 ft - 39 ft))X the porosity (0.40) or 1,014,405 acre-feet. Based upon an average specific yield of 0.14 (Appendix III), the amount of available water from this aquifer is about 355,199 acre-feet.

The Oligocene-Miocene sediments are much greater in saturated volume than the Pliocene-Holocene alluvium but contain less available water. There are approximately 22,388 acres of Oligocene-Miocene sediment surface area beneath Pliocene-Holocene alluvium on the valley floor and an additional 11,813 acres in the foothills in geologically favorable situations for containing water. Assuming that the formation is 2,500 feet thick on the valley floor and 1,000 feet thick in the foothills; that sand and gravel comprise about 1/3 of the sediments (based on drill logs), and that the saturated thickness varies from 2,500 feet on the valley floor to 700 feet in the foothills, then there are approximately 21,198,903 acre-feet of saturated Oligocene-Miocene sand and gravel in the Missoula Basin. Multiplying this quantity by an assumed porosity of 0.40 gives an estimated 8,479,561 acre-feet of water in storage. If reasonable storage coefficients of 10^{-4} and 10^{-3} are used, then there are either 2,120 or 21,199 acre-feet of available water from this formation. Using the higher figure provides a maximum estimate of available water and compensates for the uncertainty regarding the storage coefficient.

The combined amount of available water from the Pliocene-Holocene and Middle Tertiary aquifers is 376,398 acre-feet. The amount of water available from the Precambrian rock cannot be calculated, but the small specific capacity of this unit and the relatively old C^{14} age of the water in storage suggest that it contains only a small amount of available water, which will rapidly be depleted by heavy use.

Surface Water

Gaged Streams

The Clark Fork, above and below Missoula, has been gaged continuously since 1930 by the U.S. Geological Survey. The discharge at Missoula for those years is listed in Table 8. Appendix V includes average flow characteristics for the Clark Fork as it leaves the basin. The mean annual flow is 2,153,900 acre-feet above Missoula and 3,971,683 acre-feet below Missoula.

Data for the Bitterroot River at Missoula are scarce. The U.S. Geological Survey gaged the river from 1899 to 1904,

Table 8: Clark Fork Discharge at Missoula

Mean annual daily discharge[1] for water years 1930-1976

Water year	Discharge (cfs) Clark Fork Above Missoula	Discharge (cfs) Clark Fork Below Missoula	Water year	Discharge (cfs) Clark Fork Above Missoula	Discharge (cfs) Clark Fork Below Missoula
1930	2330	4220	1953	3302	5489
1931	1430	2730	1954	3106	5783
1932	2220	4250	1955	2831	5356
1933	2870	5170	1956	3646	7023
1934	3350	5875	1957	2920	5412
1935	1957	3690	1958	3043	5382
1936	2234	4277	1959	3744	6766
1937	1429	2582	1960	3178	5853
1938	2770	4999	1961	2403	4410
1939	2199	4175	1962	3167	5787
1940	1685	3068	1963	2852	5406
1941	1344	2599	1964	3568	6417
1942	2665	3020	1965	4422	7858
1943	4131	7656	1966	2612	4275
1944	2132	3540	1967	3582	6265
1945	2211	3872	1968*	2979*	5659
1946	2386	4469	1969	3710	6444
1947	3887	7367	1970	3219	5861
1948	4718	8355	1971	3777	7158
1949	2934	5649	1972	4376	8024
1950	3513	6622	1973	1788	3113
1951	4260	7551	1974	3563	7068
1952	3303	5970	1975	4468	7523
			1976	5071	8832

*Year whose discharge value is closest to the mean annual daily discharge for the 46 year period as calculated by the Log-Pearson Type III frequency analysis program version II.

[1]Data from U.S.G.S., 1955, 1960,1965,1970,1971-1974,1976,1977,1978.

but such a short record is marginally valuable in determining a mean annual flow. The U.S. Department of Agriculture (1977) estimates the flow as 1,690,000 acre-feet per year. The flow of the Bitterroot can also be estimated from data elsewhere in this report, assuming the Clark Fork flow below Missoula equals the Clark Fork flow above Missoula + the Bitterroot flow at Missoula + Tributary stream flow + irrigation ditch return + sewage inflow - consumptive use. According to this method, the Bitterroot River at Missoula has an average yearly discharge of 1,693,221 acre-feet.

Rattlesnake Creek, with a drainage basin of 79.7 square miles, has a mean annual flow at its mouth of 81,028 acre-feet. This figure was determined from gaged flows for the water years 1959 to 1967 and from linear regression against the Clark Fork discharge for the water years 1968 to 1975. However, from 1967 to 1977, Montana Power Company diverted an average 16,771 ac-ft./yr. of water from the Creek (Table 9). If the water diverted from the creek is added to the flow at its mouth, Rattlesnake Creek annually contributes 97,799 acre-feet of water to the Missoula Basin.

Table 9: Montana Power Company Annual Diversions From Rattlesnake Creek, 1967 to 1977

Year	Discharge (acre-feet)
1967	18,976
1968	18,732
1969	29,286
1970	26,717
1971	16,998
1972	15,729
1973	12,375
1974	9,414
1975	10,573
1976	12,543
1977	13,138
Mean	16,771

Ungaged Streams

Three ungaged streams enter the Missoula Basin - Grant Creek, Pattee Creek and O'Brien Creek. The mean annual discharge from these streams can be estimated using the following formula:

$$D = RAP$$

where

D = Discharge of ungaged stream

R = Rattlesnake Creek discharge per square mile of drainage area

A = drainage area of ungaged stream

P = ratio of annual precipitation in ungaged stream drainage to that in Rattlesnake Creek drainage

Rattlesnake Creek has a mean annual discharge of 97,799 acre-feet from a drainage area of 79.7 square miles. The discharge per square mile is 1,227 acre-feet. The mean annual precipitation in the Rattlesnake Creek watershed, from Figure 2, is 35.19 inches. The drainage area, mean annual precipitation, and discharge of the ungaged streams are shown in Table 10. Their combined flow is 70,676 acre-feet per year.

Table 10: Rattlesnake Creek and ungaged watershed discharge into Missoula Basin.

Creek	Drainage Area (Sq. Mi)	Mean Annual Precipitation (inches)	Mean Annual Discharge (acre-feet)	
Rattlesnake	79.7	35.19	97,799	
Grant	28.3	30.92	30,522	
Pattee	13.4	20.55	9,602	70,676
O'Brien	26.1	33.58	30,552	

Hillside Runoff

About 20 square miles of the hillsides around the basin, including McCauley Butte, drain directly into it, resulting in a small but significant recharge from overland flow. Based on a relationship between precipitation and runoff determined by the Soil Conservation Service (1971), the hillside runoff per year is estimated to be about 2,258 acre-feet (Table 11). Such runoff is seldom average, since most years have less than this value, but a few years have much more.

Table 11: Hillside Runoff in the Missoula Basin

Location	Area (Acres)	Precipitation (inches)	Runoff (feet)	Discharge (acre-feet)
North Hills	2,240	16.57	.203	454.7
Airport Ridge	2,880	14.00	.125	360.0
O'Brien Cr.-Martin Gulch Divide	576	17.68	.259	149.2
McCauley Butte	256	15.00	.150	38.4
Blue Mountain foothills	960	20.67	.404	387.8
South Hills	5,248	14.91	.147	771.5
Mt. Sentinel	6 50	15.00	.150	96.0
				2,257.6

CONSUMPTION

Residents of the Missoula Basin use 31,555 acre-feet of surface and ground water annually for a variety of purposes, which can be grouped for simplicity under two categories - agricultural and non-agricultural. There are approximately 1,140 wells in the basin (DNRC), which are divided into the following uses:

Residential	71%
Agricultural	13%
Commercial (including public)	9%
Municipal	4%
Other or not given	3%
Total	100%

Non-Agricultural Use

Municipal

About 68.3 per cent of the non-agriculturally used water is supplied by Montana Power Company. The remainder is supplied by Western Water Company (1.1%) and private sources (30.6%). Areas with municipal water supplies are shown on Plate 5.

Water furnished by Montana Power Company is diverted from Rattlesnake Creek and pumped from the valley fill. In the last 10 years, pumpage has more than doubled (Table 12). A small amount of water is stored in covered reservoirs and tanks for periods of low surface flow or heavy use (Table 12).

Table 12: Montana Power Company Water Use, 1968-1977[1]

Year	Storage (acre-ft)	Consumption (acre-feet) Pumpage	Diversions	Total
1977	8.2	15,784	13,138	28,922
1976	4.7	15,123	12,543	27,667
1975	4.7	14,843	10,573	25,416
1974	4.7	15,141	9,414	24,555
1973	4.7	15,838	12,375	28,214
1972	4.7	11,752	15,729	27,481
1971	4.6	10,453	16,997	27,454
1970	4.6	7,759	29,286	37,046

Table 12: Montana Power Company Water Use, 1968-1977[1] (continued)

Year	Storage (acre-ft)	Consumption (acre-feet) Pumpage	Diversions	Total
1969	3.8	7,681	26,717	34,398
1968	3.7	6,630	18,732	25,362

[1]Data supplied by Montana Power Company

In 1975, the latest complete year of record, 67.8% of the Montana Power Company supplied water was for residential use and 13.3% for commercial use; the remaining 18.9% seeped into the ground from leaks in the system (Appendix VI).

In 1977, Montana Power Company supplied 65.6% of the households in the Basin (Table 13). This percentage has been declining since 1970 as a result of competition from Western Water Company and private wells.

Table 13: Montana Power Company Supplied Housing in Missoula Basin[1]

Year	MPC Supplied Housing	Total Housing	%MPC of Total
1977	12,930 Units	19,709 Units	65.6
1976	12,786	19,184	66.6
1975	12,852	18,672	68.8
1974	12,594	18,174	69.3
1973	12,362	17,689	69.9
1972	12,118	17,217	70.4
1971	12,001	16,758	71.6
1970	11,730	16,311	71.9

Table 13: Montana Power Company Supplied Housing in Missoula Basin[1] (continued)

Year	MPC Supplied Housing	Total Housing	%MPC of Total
1969	11,231	15,876	70.7
1968	11,068	15,441	71.7

[1]Data from Montana Power Company and Missoula County Planning Board

Assuming there are 3.5 persons per household, the average daily consumption per person is 371 gallons. Commercial and public daily consumption per customer are 591 and 284 gallons respectively (Appendix VI).

Western Water Company supplies 400 households, with an average of 3.5 persons per household (Western Water Company, unpublished). Sprinkling and household use average 309 gallons per person per day. Thus, Western Water Company supplies 157,900,000 gallons or 486 acre-feet per year.

Private Residential

The amount of privately supplied water for residential use can be calculated from the above data. In 1977, there were 6,379 housing units not supplied by either Montana Power or Western Water Company. At 3.5 persons per unit and 371 gallons per person per day, the amount of water consumed was 3.02×10^9 gallons or 9,303 acre-feet.

Independent Commercial

The major commercial users not supplied by Montana Power Company are listed in Table 14. Their total annual use is estimated to be 59,993,163 gallons or 185 acre-feet.

Table 14: Commercial Users of water in Missoula Basin, not supplied by Montana Power Company[1]

Consumer	Gallons
Evans Products	14,920,000
Northwest Bottling	3,730,000
Daily Meats	3,000,000
Borden Chemical	3,000,000
Louisiana Pacific	7,000,000
Concrete Producers	4,675,000
VW Ice	48,000
6 schools	8,425,412
Hillside Manor	5,487,576
Miscellaneous	9,707,175
	59,993,163

[1]All estimates supplied by individual businesses except Hillside Manor, schools, and miscellaneous users. Hillside Manor and school estimates based on comparison with water use figures in Appendix VI for similar types of consumers. Miscellaneous use estimate calculated from 47 commercial/industrial wells listed in DNRC files, representing approximately 45 businesses at 591 gallons/customer/day.

Sewage

Some of the water used commercially, municipally and residentially is returned each year to the Clark Fork in the form of sewage. In 1977, 5,160 acre-feet of sewage flowed into the river. On average, 5,307 acre-feet of sewage have been produced annually from 1968 to 1977.

Irrigation

There are approximately 1,378 acres of public land within the basin which are irrigated with water pumped from wells. The major irrigators are listed in Table 15. Each year they use an estimated 3,458 acre-feet of water, based on the irrigation requirements of alfalfa, soil infiltration rates, and the efficiency of sprinkler irrigation. These data are available in U.S.S.C.S., 1972. According to Ben Hardin, of the Soil Conservation Service, sprinkler efficiences vary from 65-70% in the basin, with about 5% return to the water table by gravity and the remainder being lost to evaporation. The net annual water use, which equals the gross use less the gravity return, is 3,285 acre-feet.

Table 15: Public Land irrigation requirements in Missoula Basin

Irrigator	Area[1] (Acres)	Sprinkler[2] Efficiency (%)	Gross Annual[3] Use (Acre-feet)	Gravity Return (Acre-Feet)	Net Annual Use (Acre-Feet)
Cemetaries	78	65	609	30	579
City Parks	251	65	541	27	514
County Parks	10	65	22	1	21
UM Golf Course	340	65	734	37	697
Dornblaser Field	20	65	44	2	42
Fairgrounds	160	65	346	17	329
Missoula Country Club	82	65	177	9	168
Ft. Missoula	97	65	210	11	199
St. Forest Nursery	200	65	495	25	470
Airport	140	70	280	14	266
	1,378		3,458	173	3,285

[1]Data from Missoula County Planning Board, 1974

[2]Data from U.S. Soil Conservation Service, 1972

[3]Calculated from U.S. Soil Conservation Service umpublished data, except cemetary use, which was estimated by cemetaries

Total Use

Currently the total annual consumption of water for non-agricultural purposes is 31,555 acre-feet, as tabulated below:

Table 16: Current Annual Water Consumption in Missoula Basin

Source	Amount (Acre-feet)
Municipal (1977)	29,408
Private residential (197)	9,303
Independent Commercial (1977)	185
Public Land irrigation (avg)	3,458
MPC seepage (1977, calc.)	-5,458
MPC storage (1977)	- 8
Sewage return (1977)	-5,160
Irrigation seepage (avg)	- 173
	31,555

The annual non-agricultural use of groundwater, as tabulated below, equals 23,571 acre-feet.

Table 17: Current Annual Groundwater use in Missoula Basin

Source	Amount (Acre-feet)
Municipal (1977)	16,270
Private Residential (1975)	9,303
Independent Commercial (1977)	171
Public land irrigation (avg)	3,458
MPC Seepage (1977)	-5,458
Irrigation Seepage (avg)	- 173
	23,571

Therefore, about 75 per cent of the water consumed non-agriculturally is supplied by wells.

Agricultural Use

Stockwater

Livestock consume a small amount of water, which is pumped from wells or taken directly from streams. Gerald Marks, Missoula County Extension Agent, estimates that there are 2,000 horses and beef cattle, 100 dairy cattle, and 500 sheep, on average, within the basin. Based on water requirements for these animals, their annual consumption is about 31 acre-feet. (Table 18).

Table 18: Water Consumption by livestock in Missoula Basin[1]

Animal	Number	Daily Water Requirements (gallons)	Annual Water Use (gallons)
Horses, beef cattle	2,000	12	8,760,000
Dairy Cattle	100	35	1,277,500
Sheep	500	1	182,500
			10,220,000 gallons = 31.4 acre feet

[1]Data from Missoula County Extension Service

Irrigation

Because of the semi-arid climate, area ranchers and farmers rely heavily upon irrigation for growing their crops. Most of the irrigation water is diverted by ditches from the

Table 19 : Irrigation diversion in Missoula Basin
(from Missoula County Planning Board(1974), Montana State Engineer(1960), U.S.S.C.S., and irrigation districts)

Irrigated Area	Acres irrigated in 1959	in 1978 Total	Flood	Sprinkler	Source	Ditch Miles	Capacity (cfs)	Gross Volume (Acre-feet)	Net Use
Missoula District	2241	2000	750	1250	Clark Fork	22.2	100	9555	5360
Orchard Homes District	398	398	118	280	Clark Fork	3.9	100	1874	1076
Hellgate District	1339	1345	0	1345	Clark Fork	5.2	50	6049	3763
Grass Valley District	300	300	0	300	Clark Fork	13.5	100	1349	839
Grant Creek	2037	930	385	545	Grant Cr. & Wells	20.0	1-10	5802	2648
Rattlesnake Creek	281	186	146	40	Rattle-snake Cr.	8.0	1-4	1349	521
Miller Creek	626	167	0	167	Miller Cr.	4.0	1-10	918	484
O'Brien Creek	145	120	60	60	O'Brien Cr.	2.0	5	782	343
Total	7367	5446	1459	3987		78.8		27678	15034
Transported from the Basin									
Grass Valley District	2755	2449	2312	137	Clark Fork	13.5		6445	6292
Big Flat District	998	275	250	25	Bitterroot	9.0		779	696

Clark Fork River and Grant Creek. Some water is diverted from the Bitterroot River; O'Brien, Rattlesnake, and Miller Creeks (Table 19). A small quantity is pumped from wells, and some is pumped directly from the Clark Fork and Bitterroot Rivers (Table 21). Water is distributed to fields by sprinkler and flood methods.

There are four organized irrigation districts serving the basin - Missoula, Orchard Homes, Hellgate, and Grass Valley - and two irrigation districts transporting water from the basin to areas downvalley - Grass Valley and Big Flat. In-basin irrigation districts have 44.8 miles of main and lateral ditches providing water for 4,043 acres. Unorganized irrigators in the Hellgate Valley and the valleys of Grant, Rattlesnake, Miller, and O'Brien Creeks divert water for an additional 1,403 acres; 689 acres are irrigated by directly pumping the Clark Fork and Bitterroot Rivers. Since 1959, the amount of irrigated land in the basin has decreased by 20 per cent (Table 19). Surprisingly, the two irrigation districts now encompassing mostly urban area claim to have only slightly decreased in irrigated acreage. The land no longer being irrigated has either been subdivided, developed, or set aside for development.

Another major change since 1959 has been a large increase in sprinkler irrigation at the expense of flood irrigation because of the greater efficiency of the sprinkler method. Flood irrigation in the valley is 45 to 55 percent efficient (U.S. Soil Conservation Service, 1977); that is, only 45 to 55 percent of the water diverted is stored in the unsaturated portion of the soil for plant use. Sprinkler irrigation, on the other hand, is 65 to 70 percent efficient (U.S.S.C.S., 1972). The efficiency of each method depends on evaporation loss, soil type, and ground slope. Efficiency increases as the soil becomes finer and the ground slope gentler. At present, 76.2 percent of the irrigation is done by the sprinkler method; in 1959, however, most of the irrigation was done by the flood method. (Montana State Engineer, 1960).

No data exist on the quantity of water used for irrigation. If the capacity of all the irrigation ditches were known, a maximum amount of diverted water could be calculated assuming that the ditches were operating at full capacity. However, only the capacities of the irrigation district ditches are reliably known. Futhermore, there is no way of determining how much water is pumped from the rivers by using the ditch capacities.

Another method, which is used in this study, estimates irrigation consumption by multiplying average crop irrigation requirements, corrected for irrigation method efficiency, by the irrigated acreage. Since many irrigators locally over-irrigate, this method gives a conservative estimate of water consumed for irrigation. Alfalfa has the largest irrigation requirements of common crops grown in the valley (Soil

Conservation Service, unpublished) and is thus the most useful for estimating the quantity of irrigation water applied. Alfalfa has a growing season of 150 days and requires an average 1.61 feet of water per year at 100% efficiency. However, as the efficiency decreases, the irrigation requirement increases (Table 20).

Table 20: Average yearly irrigation requirements of alfalfa in Missoula Basin at different efficiencies[1]

Efficiency (%)	Irrigation requirements (feet/year)
100	1.61
70	2.30
65	2.48
55	2.92
45	3.58

[1]Data from Soil Conservation Service (unpublished)

Pumpage from Rivers

As seen in Table 21, 1,685 acre-feet of water per year are pumped from the Clark Fork and Bitterroot Rivers for irrigation by sprinkler methods. Assuming that 5 percent of the water pumped is lost to gravity seepage, the net use is 1,601 acre-feet.

Table 21: Estimated irrigation pumpage from rivers in Missoula Basin[1]

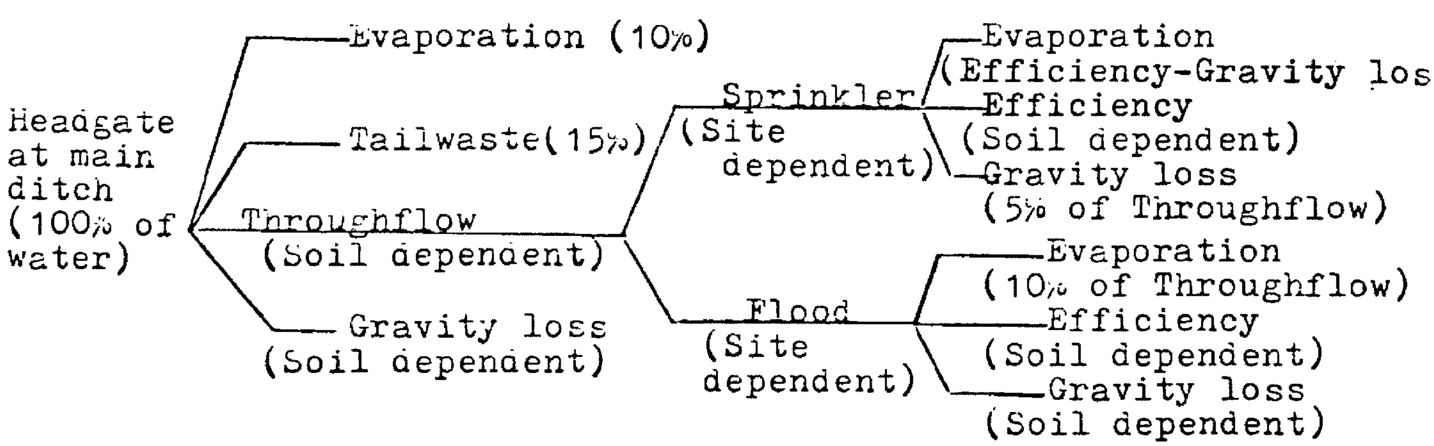
River	Total Irrigated Land (acres)	Irrigation Type: Sprinkler (acres)	Irrigation Type: Flood (acres)	Average Efficiency %	Water Pumped: Efficient use (ac-ft)	Water Pumped: Evaporation (ac-ft)	Water Pumped: Gravity return (ac-ft)	Water Pumped: Total (ac-ft)
Bitterroot	160	160	0	68	257	102	19	378
Clark Fork	529	529	0	65	850	392	65	1307

[1]Land area determined from Missoula County Planning Board (1974). Efficiency and loss percentages from Soil Conservation Service Irrigation Guide (1972) and estimates.

<u>Diversion for in-basin irrigation</u>

Only 45-55 percent of the water diverted for irrigation reaches the fields because of losses to evaporation (10%), gravity seepage (20-30%), and tail waste (15%). Tail waste is the unused water which returns to the river, or seeps into the field at the distal end of the ditch. Of the water flowing through to flood irrigated fields, another 10% evaporates, 45-55% is used by crops, and 20-30% percolates to the water table. In contrast, sprinkler irrigated fields lose only 5% of the water to gravity because water is applied more gradually and evenly, but up to 30% of the water evaporates while settling from the air. Figure 7 is a flow diagram of water efficiency and loss in a typical irrigation system.

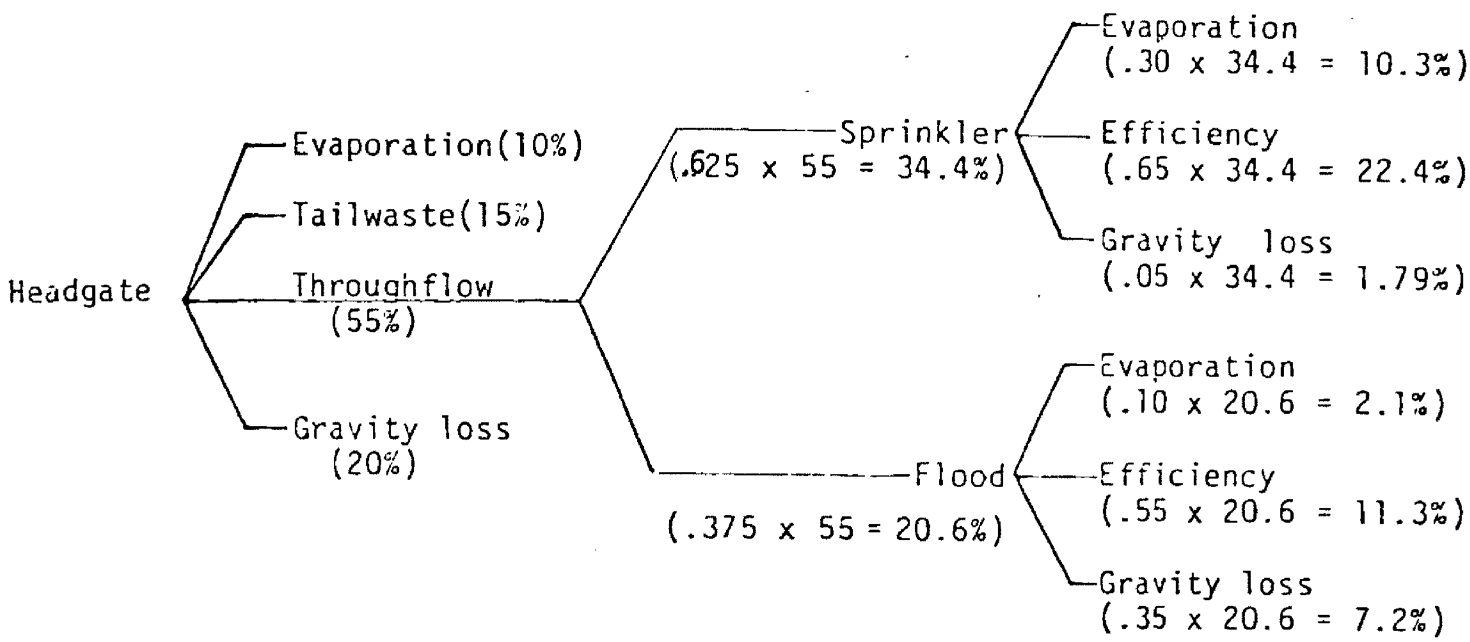
Figure 7 Generalized Irrigation System Efficiency Diagram[1]



[1]Percentages estimated by U.S. Soil Conservation Service

The consumption of water by irrigation ditch systems in the Missoula Basin is listed in Table 22. Figure 8 is a flow diagram for the Missoula District, showing how quantities were calculated.

Figure 8 Missoula District Irrigation Efficiency Diagram



In this example, the distribution of water diverted to the district is shown below in percent.

	Ditch	Sprinkler	Flood	Total
Evaporation	10	10.3	2.1	22.4
Tailwaste	15	----	----	15.0
Efficiency	--	22.4	11.3	33.7
Gravity loss	20	1.7	7.2	28.9
				100.0

Table 22: Irrigation Ditch efficiency, Missoula Basin

Area	Percent irrigated		% Efficiency		Water Use								Total Water Required
					Efficiency		Evaporation		Tail waste		Gravity Loss		
	Sprinkler	Flood	Sprinkler	Ditch	%	Ac-ft	%	Ac-ft	%	Ac-ft	%	Ac-ft	
Missoula District	62.5	37.5	65	55	33.7	3220.0	22.4	2140.3	15.0	1433.2	28.8	2761.3	9554.9
Orchard Homes District	70.4	29.6	65	55	34.2	640.8	23.2	434.7	15.0	281.1	27.6	517.1	1873.7
Hellgate District	100.0	0	65	55	35.8	2165.4	26.4	1596.8	15.0	907.3	22.8	1379.1	6048.6
Grass Valley District	100.0	0	65	55	35.8	483.0	26.4	356.2	15.0	202.4	22.8	307.6	1349.2
Grant Creek	58.6	41.4	65	45	25.8	1497.3	19.9	1151.6	15.0	870.3	39.3	2282.5	5801.7
Rattlesnake Creek	21.5	78.5	65	45	22.2	299.5	16.4	221.3	15.0	202.4	46.4	626.0	1349.1
Miller Creek	100.0	0	65	45	29.3	268.9	23.4	214.7	15.0	137.7	32.3	296.4	917.7
O'Brien Creek	50.0	50.0	65	45	24.7	193.2	19.1	149.4	15.0	117.3	41.2	322.2	782.2

Missoula Valley, Outside Basin

Grass Valley	94.4	5.6	70	55	38.0	2449.1	23.3	1501.6	15.0	966.7	23.7	1527.3	6444.7
Big Flat	90.9	9.1	65	55	35.3	275.0	25.5	198.6	15.0	116.9	24.2	188.5	779.0

Table 22 shows that 27,677 acre-feet of water are annually diverted for irrigating land within the basin. Of this quantity, 4,152 acre-feet return, mostly to the streams, as tail waste; 6,265 acre-feet evaporate; and 8,492 acre-feet seep through the unsaturated soil to the water table by gravity. The remaining 8,768 acre-feet are used by crops.

Diversion from basin

The Big Flat Irrigation District diverts water from the Bitterroot River, transporting it from the basin along 9 miles of irrigation ditch. Most of the water diverted by the Grass Valley District from the Clark Fork leaves the basin, also. The 2,714 acres of land outside of the basin which are irrigated by the Big Flat and Grass Valley Districts require 7,224 acre-feet of Missoula Basin surface water resources (Table 22). The ditch loss from seepage, per mile, is 95.5 acre-feet for the Grass Valley ditch and 17.3 acre-feet for the Big Flat Ditch. There are 1.6 miles of the Grass Valley Ditch and 4.8 miles of the Big Flat Ditch in the Missoula Basin. From the formula:

[Ditch loss/mile] x miles in study/area = ditch loss in study area, the total amount of water percolating to the water table from outgoing irrigation ditches is calculated as 236 acre-feet.

Total Agricultural Use

The total amount of water used each year for agriculture is calculated to be 23,654 acre-feet (Table 23). In fact, more water may be appropriated than is required by the crops being irrigated. However, most of the excess water will seep into the ground, eventually reaching the water table. Thus, the actual amount of water lost from the basin, as a whole, will not be much different than that calculated on the basis of crop irrigation requirements.

Table 23: Agricultural Water Use in Missoula Basin

Use	Quantity (acre-feet)
Stockwater	31
Pumpage from rivers	1,685
Diversion for in-basin use	27,678
Diversion from basin	7,224
Seepage	-8,812
Tail waste	-4,152
	23,654

WATER BUDGET

The basin-wide water budget is the yearly difference between inflow and outflow of water resources plus surface reservoir storage. If these processes are not in balance, there is assumed to be a change in groundwater storage in the basin.

In the water year, 1977-78, calculated outflow from the Missoula Basin plus reservoir storage exceeded inflow by about 21,500 acre-feet (Table 24). If this figure is accurate, it represents a 6% annual depletion of groundwater reserves stored in Missoula Basin aquifers (376,398 ac-ft). Assuming that this storage loss were evenly distributed throughout the upper valley fill, water levels in the Basin would be falling by slightly less than one foot per year. In actuality, storage losses are greatest in areas of restricted recharge, and are reflected in local depressions of the water table at times of low precipitation and runoff and heavy consumption. The large water table depression where Grant Creek enters the Missoula Valley (Plates 3 and 4) and periodically dry wells in the foothills and tributary valleys (oral communication from area residents, 1977-78) indicate locally insufficient recharge to accomodate present use in those areas.

Table 24: Water Budget for Missoula Basin, 1977-1978

Source	Water Volume (Ac-ft)
Inflow + Reservoir Storage	
Streams	4,012,375
Precipitation	24,774
Irrigation return	13,137
Municipal pipeline loss	5,458
Sewage return	5,160
Hillside runoff	2,258
Reservoir Storage	8
	4,063,170
Outflow	
Clark Fork	3,971,683
Evapotranspiration	18,872
Underground seepage	15,195
Non-agricultural Consumption	42,354
Agricultural Consumption	36,618
	4,084,722
Change in Groundwater Storage	- 21,552

The actual change in storage during the water year, 1977-1978, may differ from the calculated figure of 21,552 acre-feet because some of the assumptions used in this study may be inaccurate or over-simplified. Since the calculated storage deficit is only 0.53% of the total annual flux, it is entirely possible that there is a smaller deficit or even a net excess. This report can be interpreted to show that inflow about equalled outflow in most parts of the Missoula Basin during the 1977-1978 water year, a period of near-normal Clark Fork Basin runoff volume (Appendix V). However, this study indicates that use of water resources in the Missoula Basin, if continued at the present rate, will most likely cause local shortages of groundwater for some wells in the future. Changes in the use patterns will be necessary to avoid an increase in groundwater depletion.

SUMMARY

The Missoula Basin contains some 3,000 feet of Tertiary and Quaternary sediments. Three types of geologic units furnish water to wells. The Pliocene, Pleistocene and Holocene alluvium on the valley floor yield large quantities of water to wells from unconfined sand and gravel layers. The Oligocene-Miocene sediments in the valley and foothills yield small quantities of artesian water from sand and gravel lenses confined between impermeable clay horizons. Fractured Precambrian Belt rocks in the foothills and mountains around the Missoula Basin also yield small quantities of water.

Groundwater within all units is generally of good quality. Calcium/silica ratios in the water appear to decrease with length of storage. The combined storage of readily available groundwater in the Pliocene-Holocene alluvium and Oligocene-Miocene sediments is about 376,400 acre-feet; about 95% of this quantity is in the upper 200 feet of valley fill.

Groundwater levels fluctuate seasonally, annually, and with distance from recharge areas. On average, peaks and troughs in groundwater hydrographs during any one year are separated by 3.5 months and are 10 feet apart in elevation. Water levels are most often at their maximum in June and at their minimum in April. During the water year 1977-1978, the water table was never greater than 96 feet deep in the center of the basin and 20 feet deep near the Clark Fork and Bitterroot Rivers. Seasonal fluctuations of 12 to 44 feet in the valleys of Grant, Rattlesnake, and Butler Creeks reflect the influence of high Spring runoff in these valleys upon recharge. Groundwater movement is predominantly southwestward towards the Clark Fork and Bitterroot Rivers, but these rivers are influent within the basin. The average discharge and velocity of groundwater through the urban area are, respectively, 5,142,000 ft^3/day and 6.2 ft/day.

Most of the surface water entering the basin is from the Clark Fork and Bitterroot Rivers, but a significant amount also comes from Rattlesnake, Grant, Pattee, and O'Brien

Creeks. Total streamflow into the basin equals 4,012,375 acre-feet/year. Most of the precipitation, which annually ranges from 12 to 15 inches, evaporates or is used by plants before infiltrating into the ground. About 5,900 acre-feet of precipitation reaches the water table directly each year. A small amount of precipitation (2,300 acre-feet) infiltrates the ground from hillside runoff. Groundwater recharge from irrigation annually equals about 8,800 acre-feet. An average 8 acre-feet/year of water is stored in small surface reservoirs.

Water escapes from the basin by flowage out the Clark Fork River and irrigation ditches, subsurface seepage, and appropriation for agricultural, residential, public, and commercial use. Clark Fork outflow averages 3,971,683 acre-feet/year; underground seepage is estimated as 15,195 acre-feet/year. Consumption for agricultural and non-agricultural purposes annually amounts to about 55,000 acre-feet after return of some water to the ground and streams from irrigation, sewage outflow, and water pipeline losses.

Outflow from the basin currently exceeds inflow by a slight amount, resulting in an estimated annual groundwater storage deficit of about 21,500 acre-feet. The total estimated inflow plus reservoir storage equals 4,063,170 acre-feet, while the total outflow equals 4,084,722 acre-feet. As a result, some areas with restricted recharge experience depressions in the water table during periods of low precipitation and stream runoff, especially where agricultural or residential use is heavy. Such a depression occurs near the mouth of the Grant Creek valley as a result of heavy irrigation withdrawal.

Continually growing reliance upon groundwater to meet the needs of an expanding population and to increase agricultural efficiency in the Missoula Basin most likely will lower the water table in some areas, causing some shallow wells to go dry. The deeper municipal supply wells should not be affected by these deficits, which could locally be on the order of 10-15 feet. Future wells supplying large amounts of water for agricultural or non-agricultural use should be located in areas of reliably rapid recharge, such as the Clark Fork and Bitterroot floodplains. Utilization of the Oligocene-Miocene and Precambrian rocks as sources of groundwater should be discouraged because water in these formations occurs sporadically and provides small sustained yields. Moreover, wells penetrating the Oligocene-Miocene aquifer in the foothills, are susceptible to contamination by septic tank failure as a result of the formation's inability to drain efficiently. Missoula is fortunate to have a large supply of high quality water resources, and sound planning will assure their continued availability in the future.

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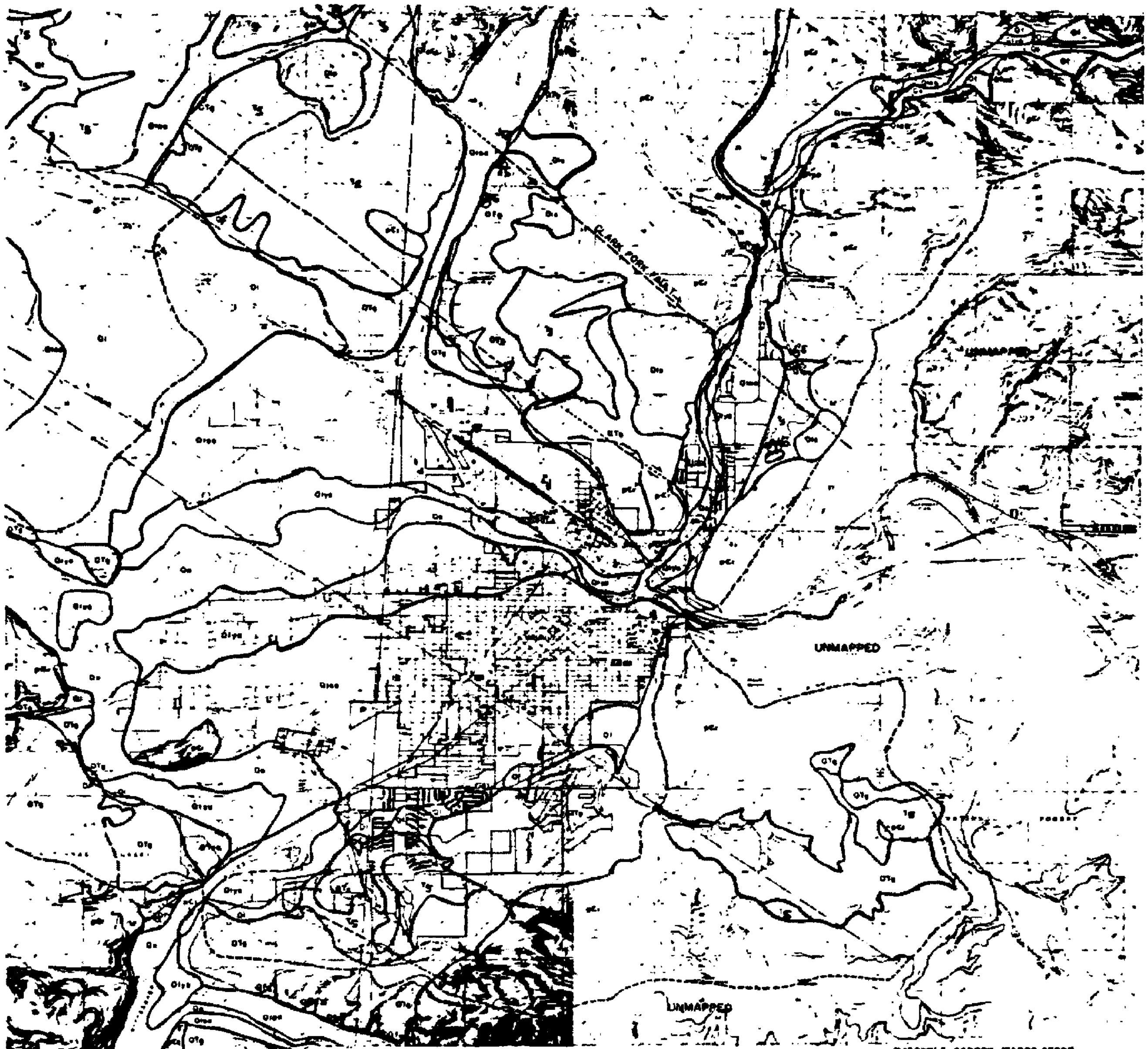


Plate I
Generalized
Geologic Map of Missoula Basin,
Missoula County, Montana

Prepared by
Arthur L. Golden
1978
Drafting–John Castle

Legend

Quaternary: Holocene — Qa Active Alluvium; Pleistocene — Qf Fan Alluvium; Qtoa Older Terrace Alluvium; Ql Lake Sediments

Plio-Pleistocene — QTg Bench Gravels

Tertiary: Miocene-Oligocene? — Tg Renova Formation Equivalent (… Kuenzi and Fields, 1971)

Precambrian basement — pЄ Belt Series – Missoula Group and Wallace Formation (includes minor Cambrian limestone)

Qls Landslide deposits

Qtya Younger terrace alluvium

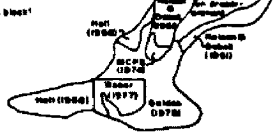
Qt Glacial till

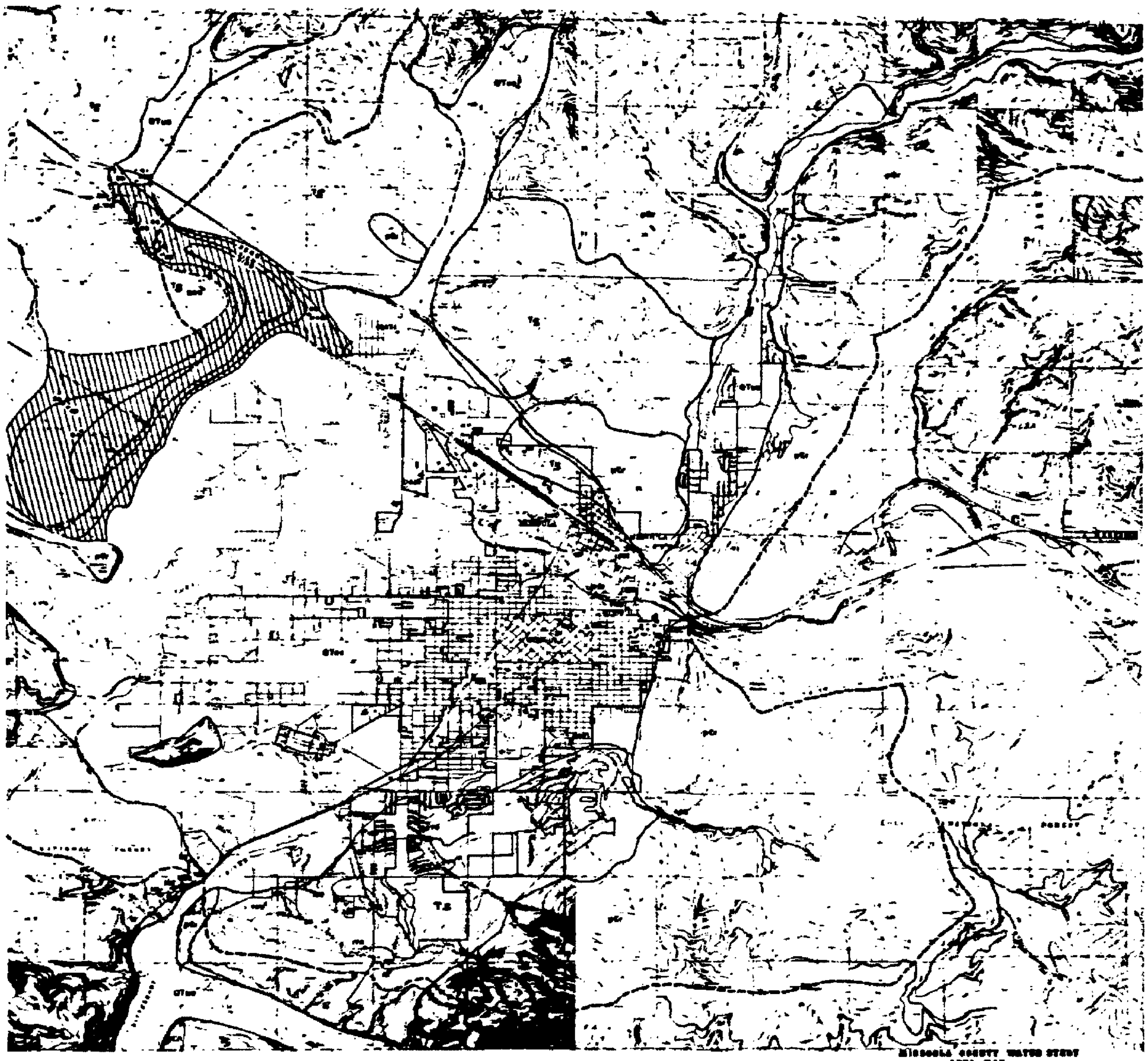
Formation contact, dashed where inferred

Normal fault (high angle)

Thrust fault (teeth on upthrown block)

Watershed boundary





MISSOULA COUNTY WATER STUDY
AREA MAP

Scale: [illegible]

Plate 2
Aquifer Map

Prepared by
Arthur L. Geldon
1976
Drafting—[illegible]

Legend

Available water in fractured zones within and at surface of Precambrian bedrock K = 10^{-5} to 5 (m./hr.) C = 10^{-4} to 0.3 (m./hr.)
70 Depth to water bearing strata in wells

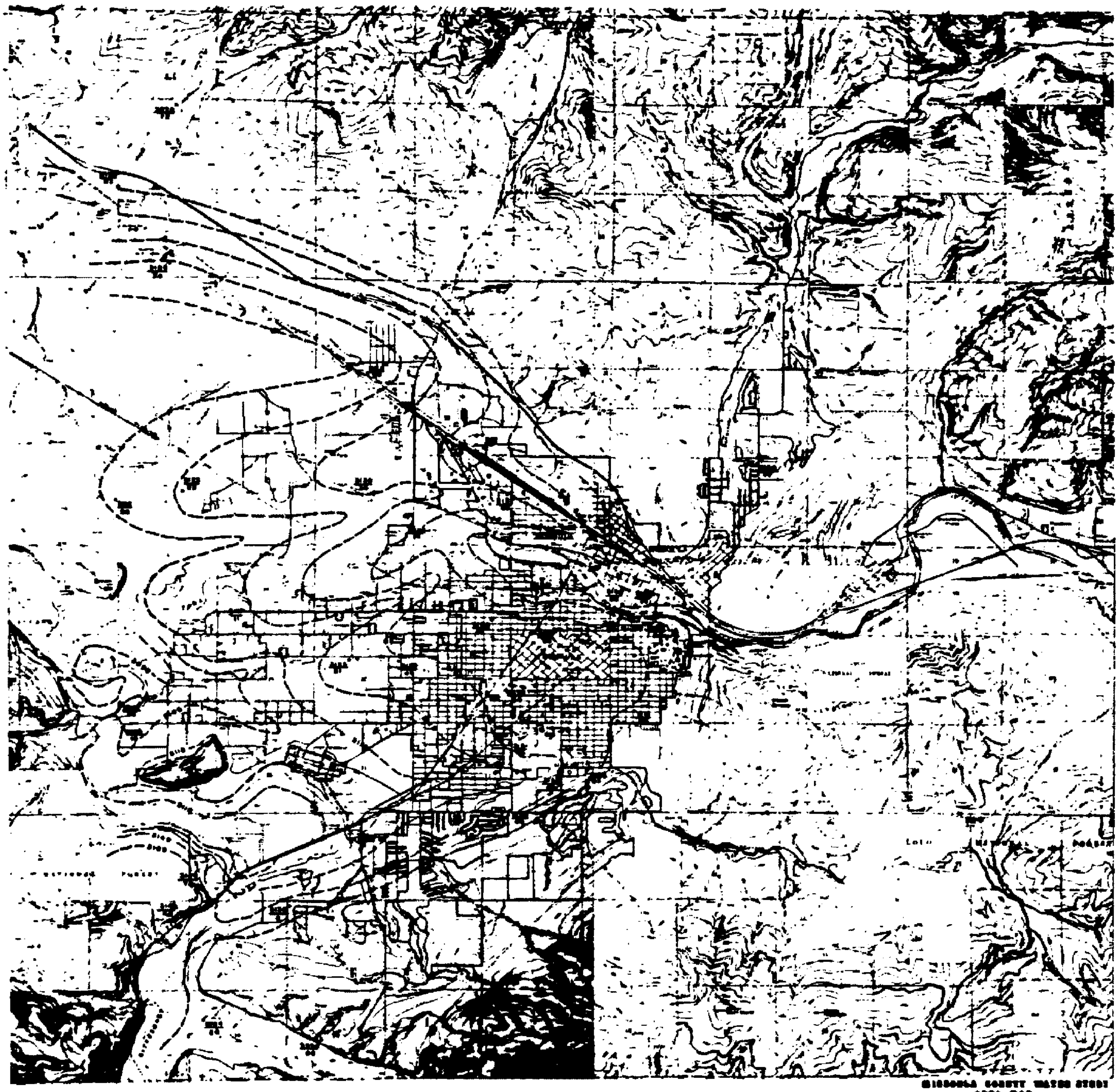
Available water in sand and gravel layers and lenses in Tertiary strata K = 1 to 30 (m./hr.) C = 10^{-2} to 0.3 (m./hr.)
80 Depth to water bearing zone in wells

Available water in Quaternary and [illegible] Tertiary (Pliocene) sand and gravel alluvium K = 1 to 3000 (m./hr.) C = 1 to 3000 (m./hr.)
90 Depth to aquifer where buried beneath lakebeds
(120) Known thickness

Elevation contour on buried Quaternary aquifer surface

Watershed boundary

K = Hydraulic Conductivity (m./hr.)
C = Specific Capacity (discharge in GPM. per foot of drawdown)



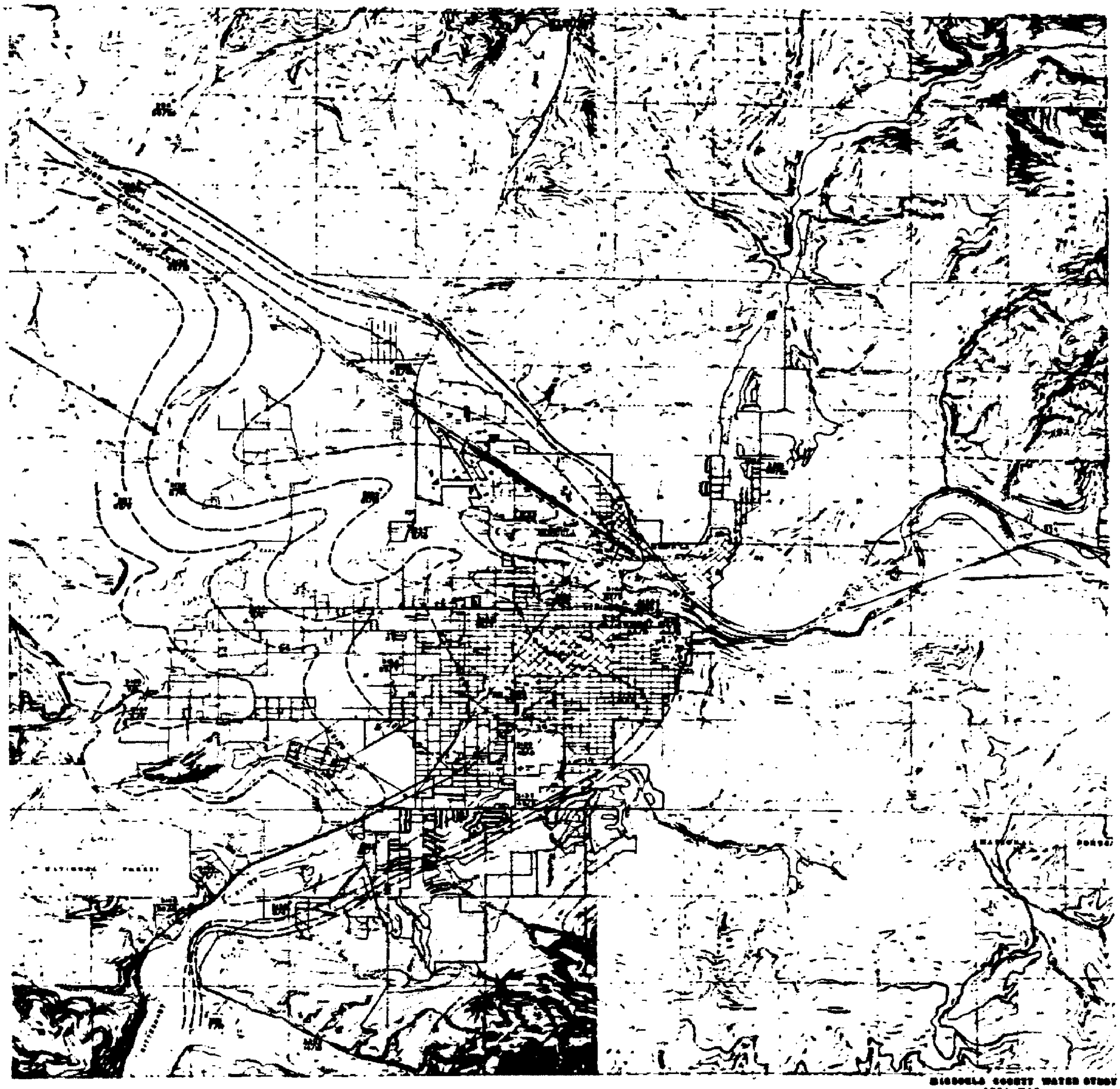
MISSOULA COUNTY WATER STUDY
AREA MAP

Piezometric Surface
on March 1, 1978
(Lowest water table
October, 1977 to September, 1978)

Scale: 1"=4000'

Plate 3

—3110— Water table contour (feet)
3140 = Elevation of water table
24 = Depth to water



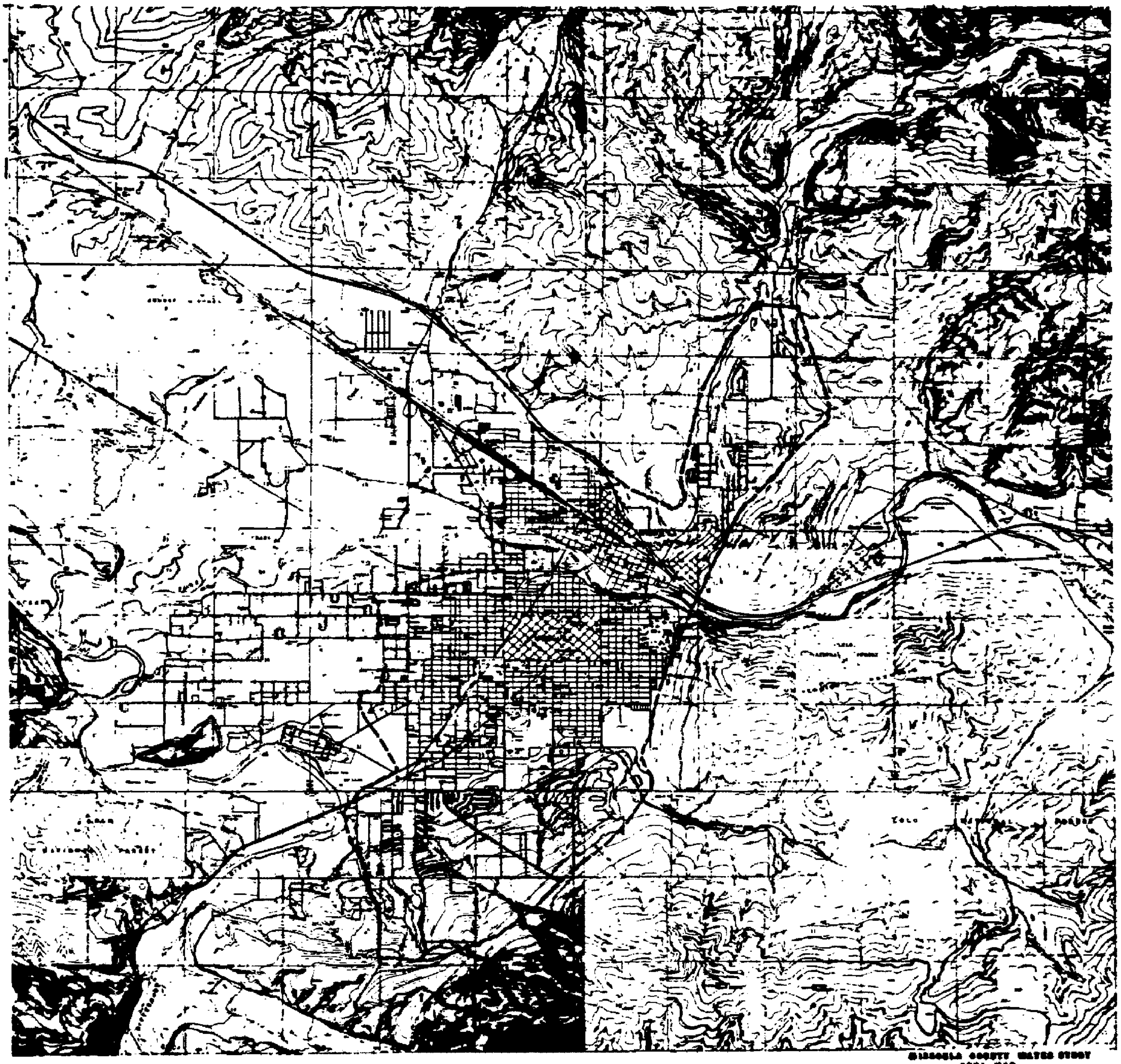
MISSOULA COUNTY WATER STUDY
AREA MAP

Scale: 1"=4000'

Plate 4

Piezometric Surface
about July 15, 1978
(Highest water table
October, 1977 to September, 1978)

—3116— Water table contour (feet)
* 3140 = Elevation of water table
36/10 = Depth to water / Seasonal fluctuation
(for basic observation well network)



MISSOULA COUNTY WATER STUDY AREA MAP

Plate 5 Missoula Basin Water Supply Districts

Information supplied by [illegible]
Water Engineer
Montana Power Co.

Drafting [illegible]

Supplied by MONTANA POWER COMPANY
Supplied by WESTERN WATERS

APPENDICES

Appendix I: Drill logs of Missoula Basin Wells

Owner: Montana Power Company; Missoula, Montana.

Well: MP-29; T12N, R20W, S1NE

Driller: Camp Well Drilling and Pump Supply

Date Started: 5/25/73

Date Completed: 6/20/73

Equipment: Churn Drill

Size of hole	Casing Depth	Peforations
16"	136'	100-125'

Pumptest Data

Static Water level:	24'
Pumping Water level:	35'
Yield:	1000 GPM
Duration of Test:	4 hours

LOG

Ground elevation 3150 ft

Depth		Unit
0-1	Black Topsoil	Soil
1-5	Sandy clay	older terrace alluvium
5-24	Sand and gravel, water below 15'	
24-33	Clay and gravel	
33-35	Sand and water	
35-49	Sand, gravel and water	
49-64	Sand and clay	
64-68	Sand, gravel and water	
68-75	Clay and gravel	
75-78	Sand and water	
78-84	Sand, gravel, water	
84-90	Sand, gravel & seams of clay; water	bench gravels
90-125	Sand, gravel, water	
125-136	Gray clay with gravel	Oligocene-Miocene sediments

Bottom at 136'

Owner: Blanche V. and William J. Wheeler, Missoula, Montana

Well Location: T13N, R19W, S6NW

Driller: Liberty Drilling Company

Date Started: 1/11/73

Date Completed: 2/15/73

Equipment: Air rotary drill & cable tools

Size of hole	Casing depth	Perforations
12"	174'	168-203'

Pump test data

Static water level: 83'
Pumping water level: 138'
Yield: 600 GPM
Duration of test: 66.5 hours

LOG

Depth		Ground elevation 3210' Unit
0-1	Topsoil	Soil
1-53	Tan clayey silt	Lacustrine sediments
53-139	Gravel, cobbles, & boulders in tan clayey silt	Bench gravels
139-166	Silty sand and gravel with cobbles	
166-191	Sand and gravel, water	
191-198	Silty sand and gravel, seeps of water	
198-203	Light gray clay with gravel	Oligocene-Miocene sediments

Owner: Montana Power Company, Missoula, Montana
Well: MP-17; T14N, R20W, S35NW
Driller: Camp Well Drilling & Pump Supply
Date Started: 8/8/68
Date Completed: 10/30/68
Equipment: Churn Drill

Size of hole	Casing Depth	Peforations
16"	360'	177-181'
		319-324'
		335-344'

Pump test data

Static Water Level:	107'
Pumping Water Level:	113'
Yield:	500 GPM
Duration of Test:	$6\frac{1}{2}$ hours

Log

Ground Elevation 3238'

Depth	Log	Unit
0-1	Topsoil	Soil
1-79	Gravel and Clay	Bench gravels
79-85	Sand and Gravel with water	
85-90	Silty Sandy gravel	
90-104	Clay	
104-106	Sand and gravel with water	
106-130	Clayey gravel	
130-132	Sand and gravel with water	
132-157	Clayey Gravel	
157-171	Clay	
171-179	Sand, gravel, water	
179-189	Clay, sand, Gravel	
189-236	Blue and yellow clay	Oligocene-Miocene sediments
236-240	Gravel and Clay	
240-252	Gray clay	
252-253	Sand, yellow clay, water seep	
253-270	Clay	
270-289	Brown clay & Sandy Clay	
289-299	Sand, Gravel, water	
299-302	Clay and gravel	
302-335	Sand, gravel, clay, water	
335-338	Tan clay	
338-346	Gravel, sand, some clay, water	
346-360	Gravel, sand, clay	

Bottom at 360 feet

Owner: Elva H. and Robert C. Runke; Missoula, Montana

Well location: T13N, R19W, S12NW

Driller: Liberty Drilling Co.

Date Started: 2/19/64

Date Completed: 5/19/66

Equipment: Cable tools and air rotary drill

Size of hole	Casing depth	Peforations
6"	333'	None

Pump test data
- Static water level: 65'
- Pumping water level: 495'
- Yield: 6 GPM
- Duration of test: 24 hours

Log

Ground Elevation 3430'

Depth		Unit
0-6	Topsoil	Soil
6-73	Boulders and cobbles in tan silty clay	Bench gravels
73-84	Brown and gray clay with gravel	Oligocene-Miocene sediments
84-93	Gray clay with gravel and boulders	
93-116	Lavender and gray clay with gravel and cobbles	
116-149	Gray clay with gravel and cobbles water in gravel at 144'	
149-171	Dark brown clay and tin silty clay	
171-203	Gray and brown clay with gravel	
203-254	Gray and black clay with gravel	
254-289	Lavender and gray clay with gravel	
289-301	Gray clay with gravel	
301-306	Green clay with gravel	
306-332	Tan clay with gravel	
332-1145	Gray, green and brown argillite; water in cracks below 431'	Wallace Fm.

Owner: Lucina S. and John F. Boyle

Well Location: T12N, R20W, S10NE

Driller: Liberty Drilling Co.

Date Started: 5/10/65

Date Completed: 5/18/65

Equipment: Air rotary drill

Size of Hole	Casing depth	Peforations
6"	133.5'	131-219'

Pump test data

Static Water Level:	81'
Pumping water Level:	185'
Yield:	16 GPM
Duration of test:	6 hours

Log

Depth		Ground elevation 3240' Unit
0-2	Topsoil	Soil
2-158	Red argillite, water 24-32'	Missoula Group
158-219	Red and Green Argillite in layers 2-4 feet thick; Fractured, water in cracks and seams	

Bottom at 219'

Appendix II. Methods of Calculating Drawdown, Specific Capacity, Hydraulic Conductivity, and Transmissivity from Pump Test Data (after Jacob, 1963a, 1963b)

1. Drawdown

$$s' = s - s^2/2m$$

where

s = measured drawdown (ft)
s' = drawdown in equivalent confined aquifer (ft)
m = aquifer thickness (ft)

2. Specific Capacity

a) $C = Qo/s'$

b) $$Qo = \frac{Q}{\alpha[1+7(r_w/2\alpha m)^{1/2} \times \cos(\frac{\pi\alpha}{2})}$$

where

C = Corrected specific capacity (GPM/ft)
Q = measured discharge from pump (GPM)
Qo = discharge from equivalent, fully penetrated aquifer (GPM)
α = fraction of aquifer penetrated
r_w = radius of well (ft)
s', m as above

3. Transmissivity

$$C = \frac{12.56T}{\ln \frac{(2.25T+)}{(r_w^2 S)}}$$

where

T = Transmissivity (GPD/ft) C, r_w as above
$+$ = duration of pump test (days)
S = Storage coefficient or specific yield

4. Hydraulic Conductivity

$$K = T/m$$

where

K = hydraulic conductivity (GPD/ft^2)
T,m as above

1 GPD/ft^2 = .134 ft/day = .067 in/hr.

Appendix III Hydrologic properties of aquifers determined from pump tests on individual wells.

Pliocene-Holocene

Well	m (ft)	∝	Qo (GPM)	s[1] (ft)	t (days)	C (GPM/ft)	S	rw (ft)	T (GPD/ft)	R (ft/day)	R (in/hr)
P-30	98	1	2,000	9.49	.125	210.7	0.14	.75	285,737	391.4	195.7
P-31	118	1	4,100	14.05	.08	291.8	0.11	.75	400,162	455.2	227.6
MP-32	129	1	1,500	0.50	.125	300.0	0.14	.75	5,056,352	5,261.3	2,630.7
MP-25	137	1	1,000	24.98	.25	40.03	0.35	.6	47,047	46.1	23.1
MP-18	125[1]	.84	855	7.74	.31	110.5	0.22	.65	151,228	162.4	81.2
MP-19	160[1]	.68	1,064	3.36	.08	316.7	0.11	.65	448,773	376.5	188.3
MP-20	160[1]	.90	833	8.75	.17	95.20	0.16	.65	125,086	104.9	52.5
MP-21	140[1]	.98	763	5.58	.02	136.7	0.06	.65	165,874	159.0	79.5
MP-26	130[1]	.96	981	2.38	.33	412.2	0.23	.65	632,334	652.9	326.5
MP-27	170[1]	.74	1,475	1.00	.25	1,475	0.20	.65	2,470,822	1,950.9	975.5
MP-29	125	1	1,000	10.52	.17	95.06	0.16	.65	124,907	134.1	67.1
MP-33	150[1]	.98	1,504	1.00	.04	1,504	0.08	.75	2,298,288	2,056.6	1,028.3
MP-13	200[1]	.64	1,014	51.0	.29	19.88	0.22	.5	24,049	16.1	8.1
Wheeler (SE)	243	1	600	34.18	3.1	17.55	0.35	.5	26,865	14.8	10.5
Van Evan	245[1]	.91	125	48.83	.17	2.56	0.16	.5	2,347	1.29	7.4
M & S	230[1]	.84	441	80	.25	5.51	10^{-2}	.35	9,879	5.77	0.65

Appendix III - Continued

Pliocene-Holocene

Well	m (ft)	α	Qo (GPM)	s[1] (ft)	t (days)	C (GPM/ft)	S	rw (ft)	T (GPD/ft)	R (ft/day)	R (in/hr)
Wheeler(NW)	145	1	600	55	2.76	10.91	10^{-2}	.5	22,693	21.0	2.9
El Mar (SW)	120[1]	.57	844	4	.33	211.0	10^{-2}	.35	478,528	535.3	267.7
El Mar (SE)	120[1]	.53	897	4	.33	224.1	10^{-2}	.35	509,871	570.3	285.2
Average	151		1137	19.28		430.4			699,927	679.8	339.9

Oligocene-Miocene sand and gravel

Well	(ft)	α	Qo (GPM)	s[1] (ft)	t (days)	C (GPM/ft)	S	rw (ft)	T (GPD/ft)	K (ft/day)	K (in/hr)
Morton	5	1	10	90	.19	0.111	10^{-4}	.42	182.5	4.29	2.15
Brackebush	10	1	30	15	.17	2.00	10^{-4}	.50	3,956	53.1	26.6
✓ MP-28	3	1	33	38	.83	0.868	10^{-4}	.50	1,557	69.7	34.9
Taggert	5.5[2]	1	2.24	48	.15	0.047	10^{-4}	.50	78.2	1.91	0.96
Shaner	2.0[2]	1	5.0	150	.29	0.033	10^{-4}	.50	51.4	3.46	1.73
Tucker	2.0[2]	1	3.45	135	.17	0.026	10^{-4}	.50	37.3	2.48	1.24
Average	4.6		13.9	79		0.514			979	22.5	11.3

Appendix III - Continued

Precambrian rock

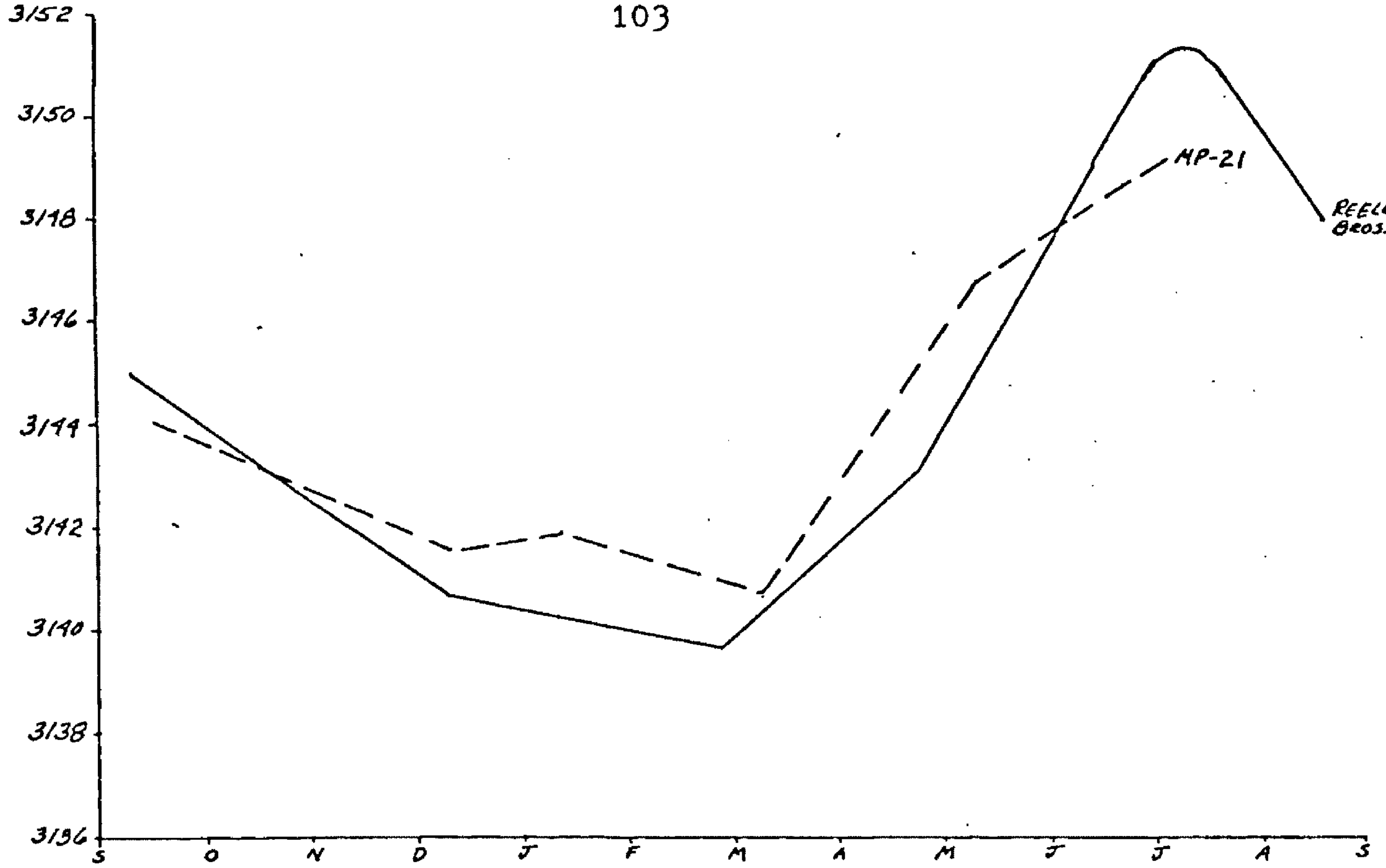
Wells	m (ft)	$\propto$	Qo (GPM)	s^1 (ft)	t (days)	C (GPM/ft)	S	rw (ft)	T (GPD/ft)	K (ft/day)	K (in/hr)
reenwood	120	1	16	122	.67	0.131	10^{-5}	.25	275.7	0.31	0.16
toddard	8	1	17	78	.25	0.218	10^{-5}	.25	444.8	7.46	3.73
Carlson	123	1	7	78	.13	0.090	10^{-5}	.3	161.7	0.18	0.09
Inabnit	8	1	20	222	.50	0.090	10^{-5}	.25	181.8	3.05	1.53
Means	4	1	18	190	.25	0.095	10^{-5}	.25	166.9	5.60	2.80
Runke	714	1	6	430	1.0	0.014	10^{-5}	.25	26.1	0.005	0.003
Average	163		14	187		0.106			210	2.77	1.39

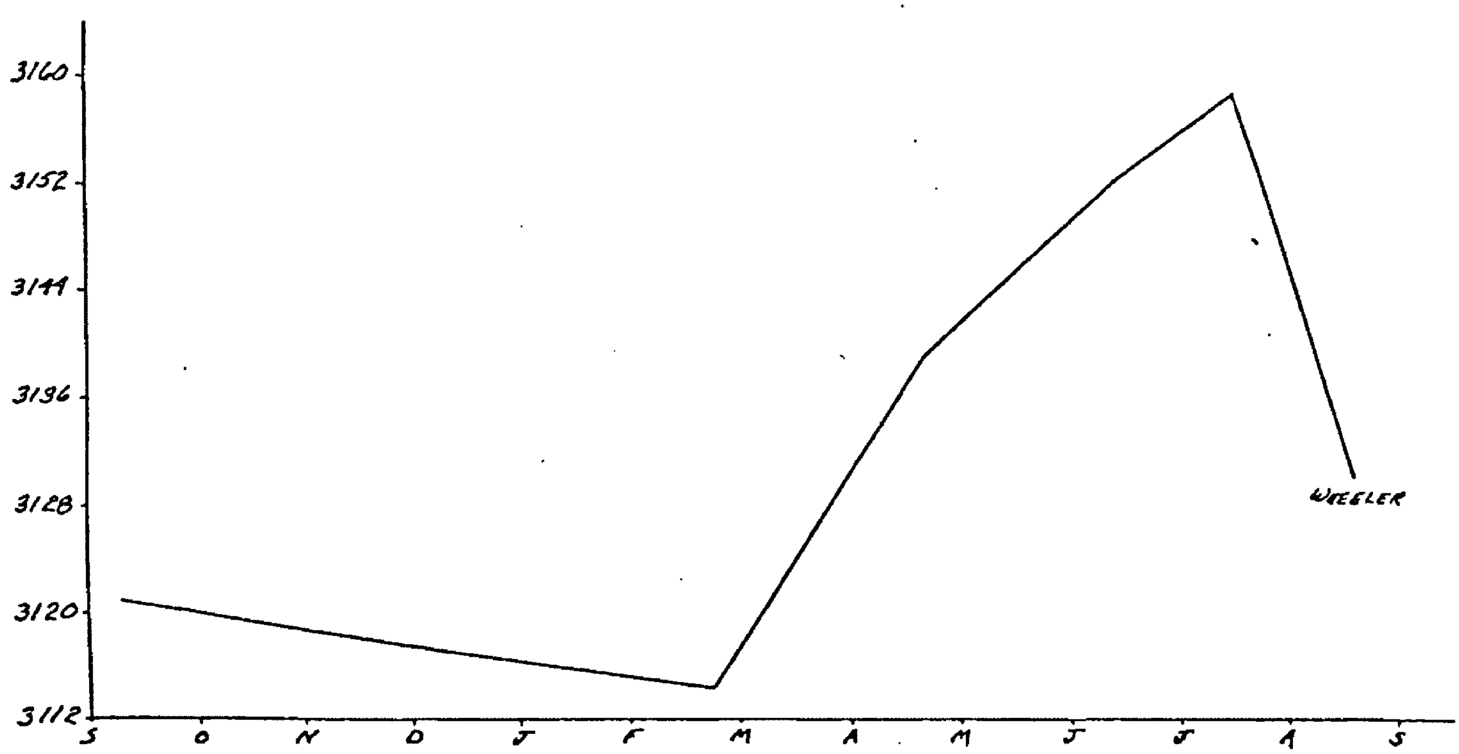
m = Thickness of aquifer or water-bearing layer.
$\propto$ = Fraction of aquifer penetrated by well.
Qo = Corrected discharge.
s' = Corrected drawdown.
t = Length of time pumped.
rw = Radius of well.
T = Transmissivity.
C = Specific capacity.
K = Hydraulic conductivity.
S = Storage coefficient.

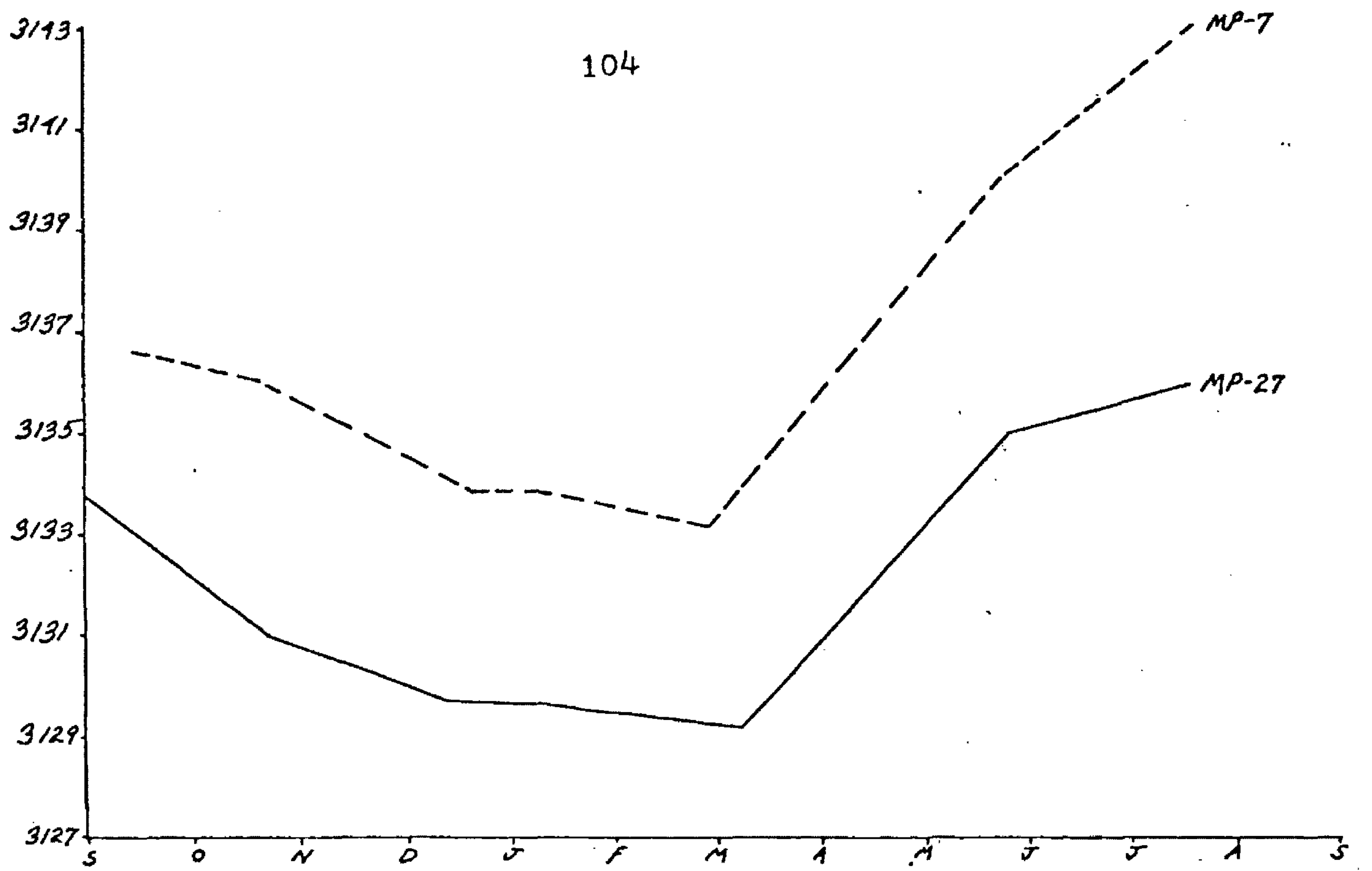
Thickness estimated from drill logs and cross sections.
Thickness used is the average thickness of water-bearing sand and gravel layers in the well.

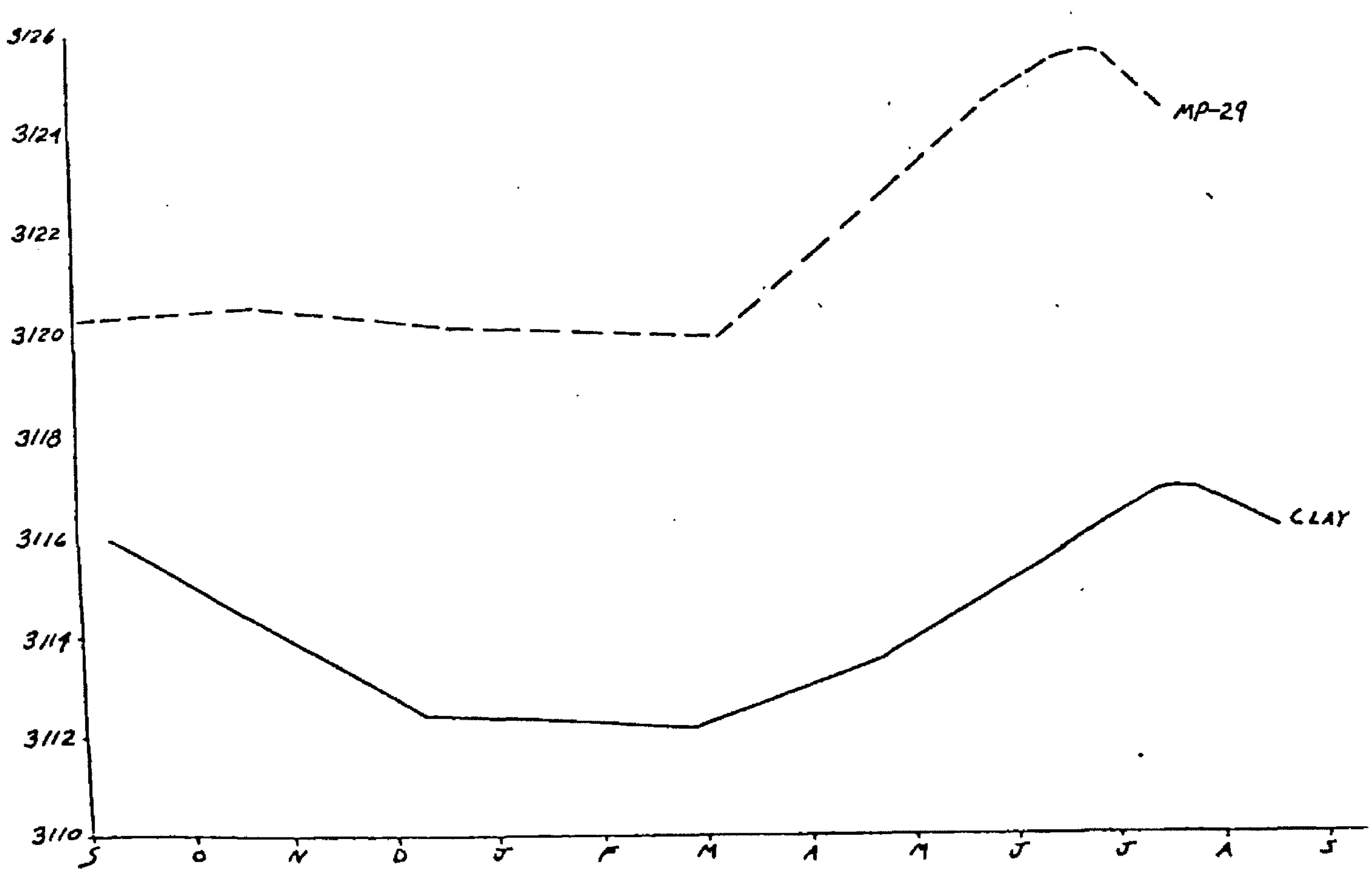
APPENDIX IV

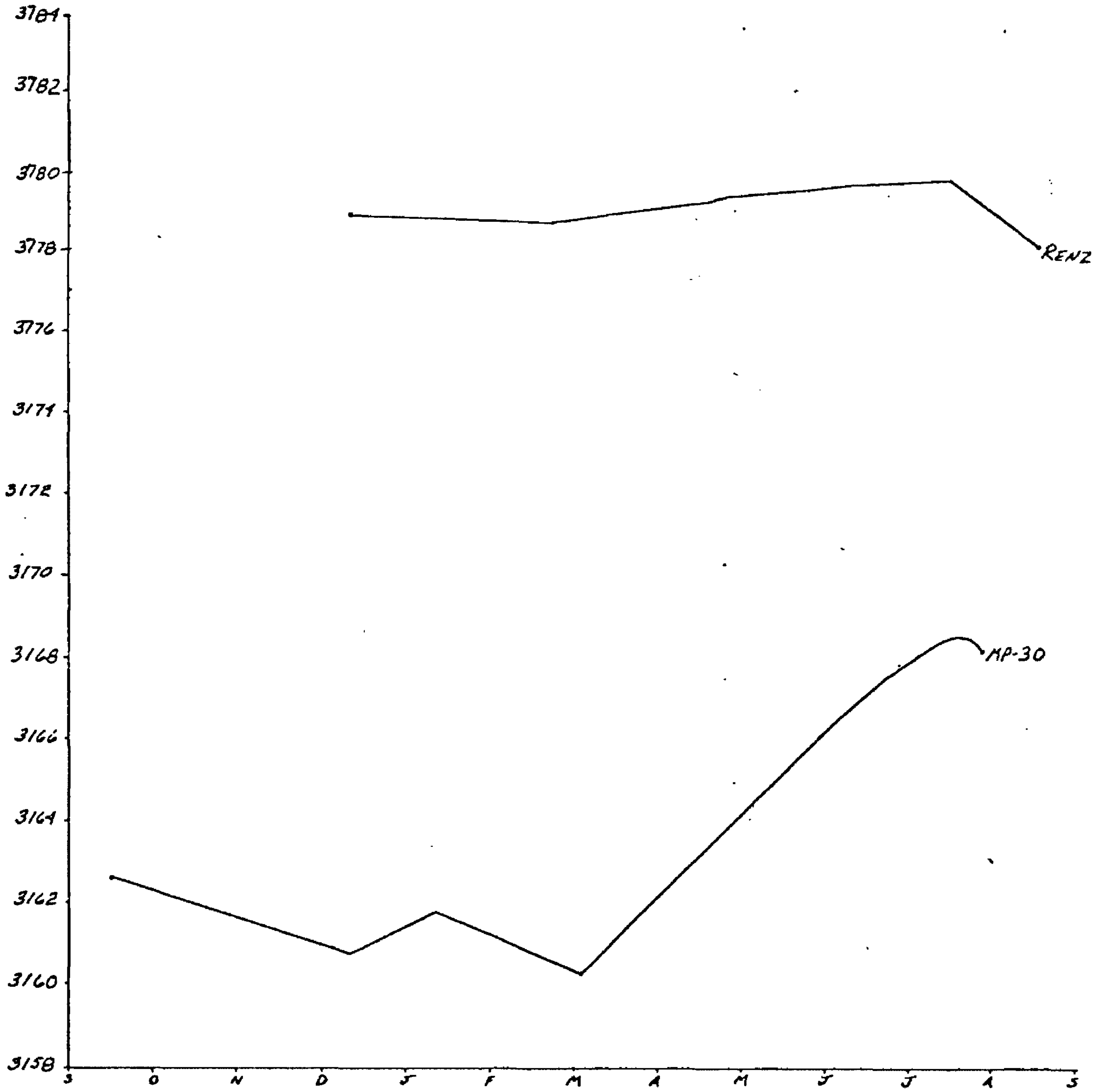
Groundwater Hydrographs for Selected Missoula Basin Wells

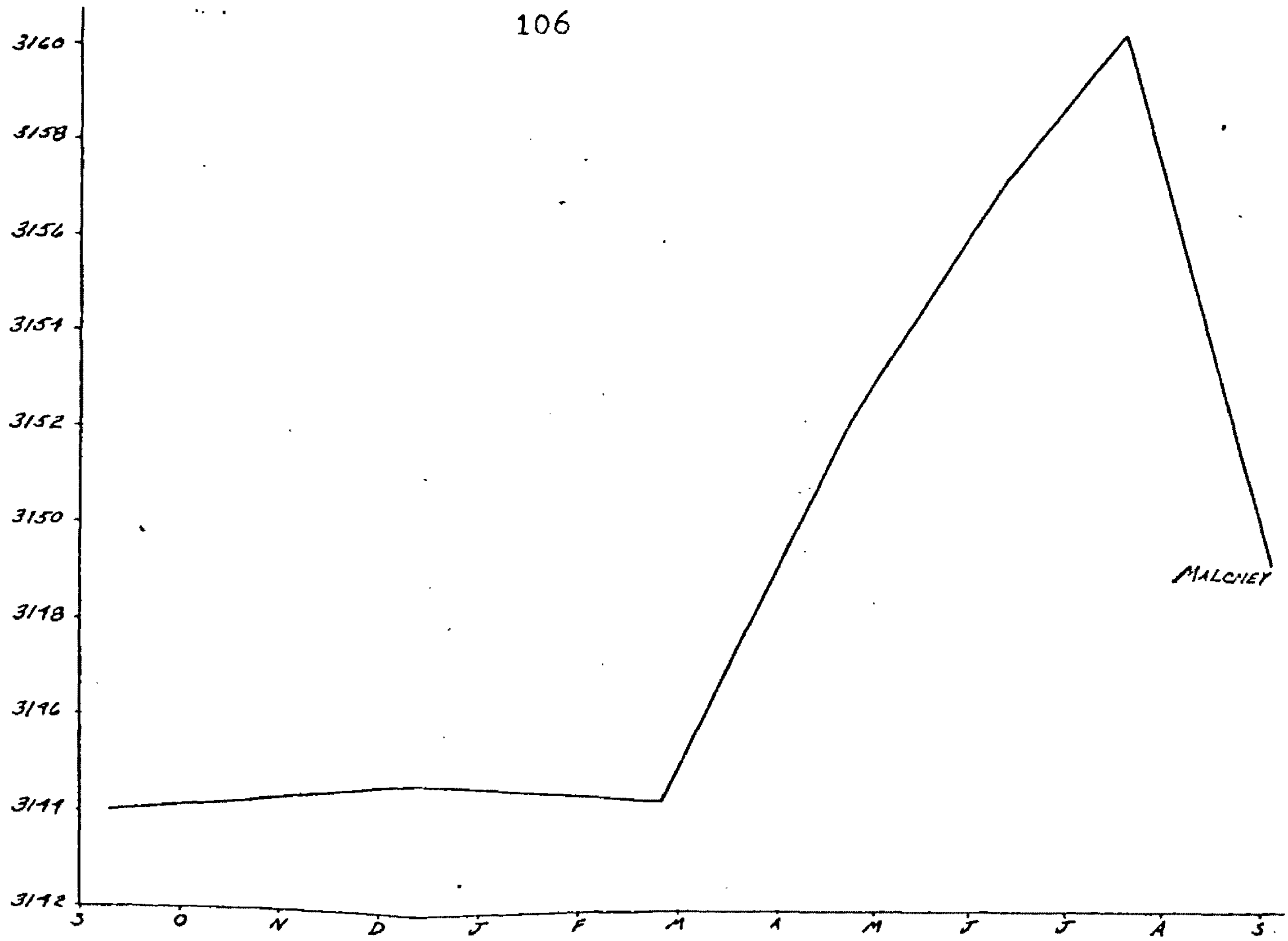

3152
3150
3148
3146
3144
3142
3140
3138
3136
S O N D J F M A M J J A S
MP-21
REELEY BROS.

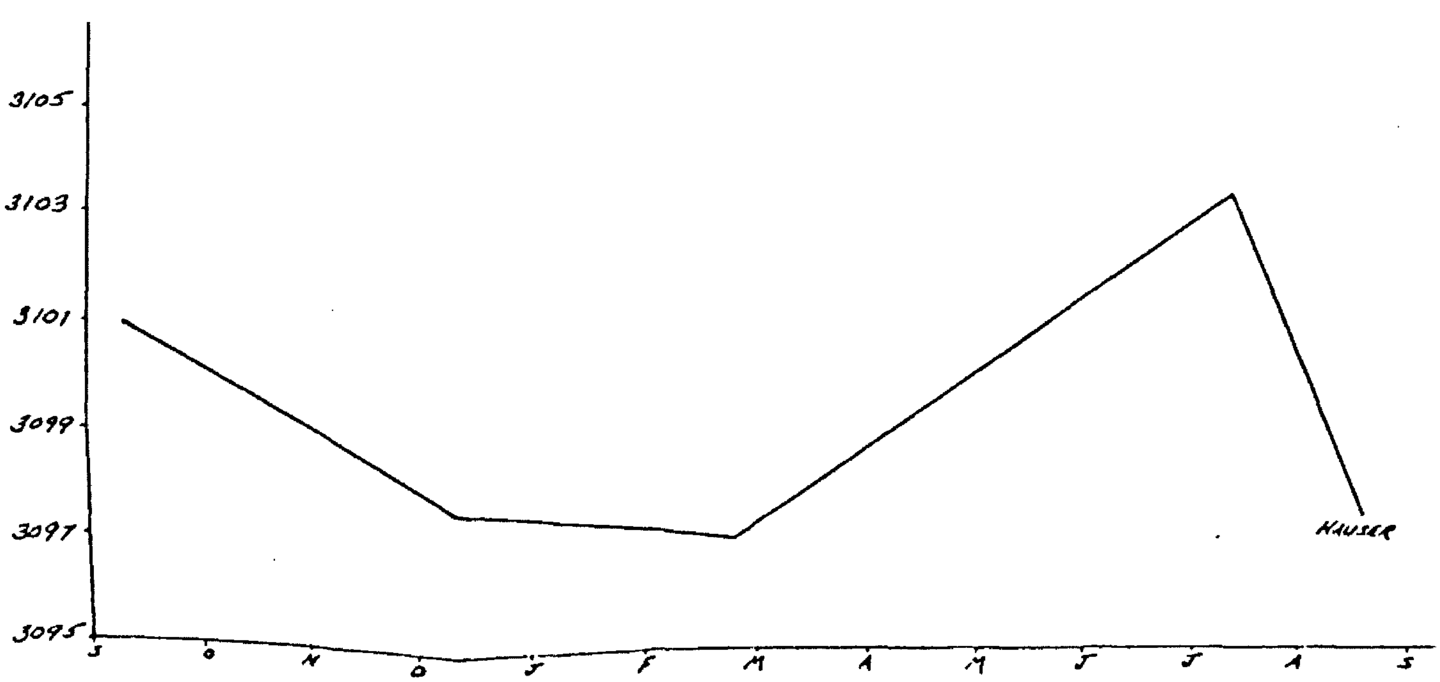

3160
3152
3144
3136
3128
3120
3112
S O N D J F M A M J J A S
WHEELER


3143
3141
3139
3137
3135
3133
3131
3129
3127
MP-7
MP-27
S O N D J F M A M J J A S


3126
3124
3122
3120
3118
3116
3114
3112
3110
MP-29
CLAY
S O N D J F M A M J J A S


3784
3782
3780
3778
3776
3774
3172
3170
3168
3166
3164
3162
3160
3158
S
O
N
D
J
F
M
A
M
J
J
A
S
RENZ
MP-30


3160
3158
3156
3154
3152
3150
3148
3146
3144
3142
S
O
N
D
J
F
M
A
M
J
J
A
S
MALONEY


3105
3103
3101
3099
3097
3095
S
O
N
D
J
F
M
A
M
J
J
A
S
HAUSER

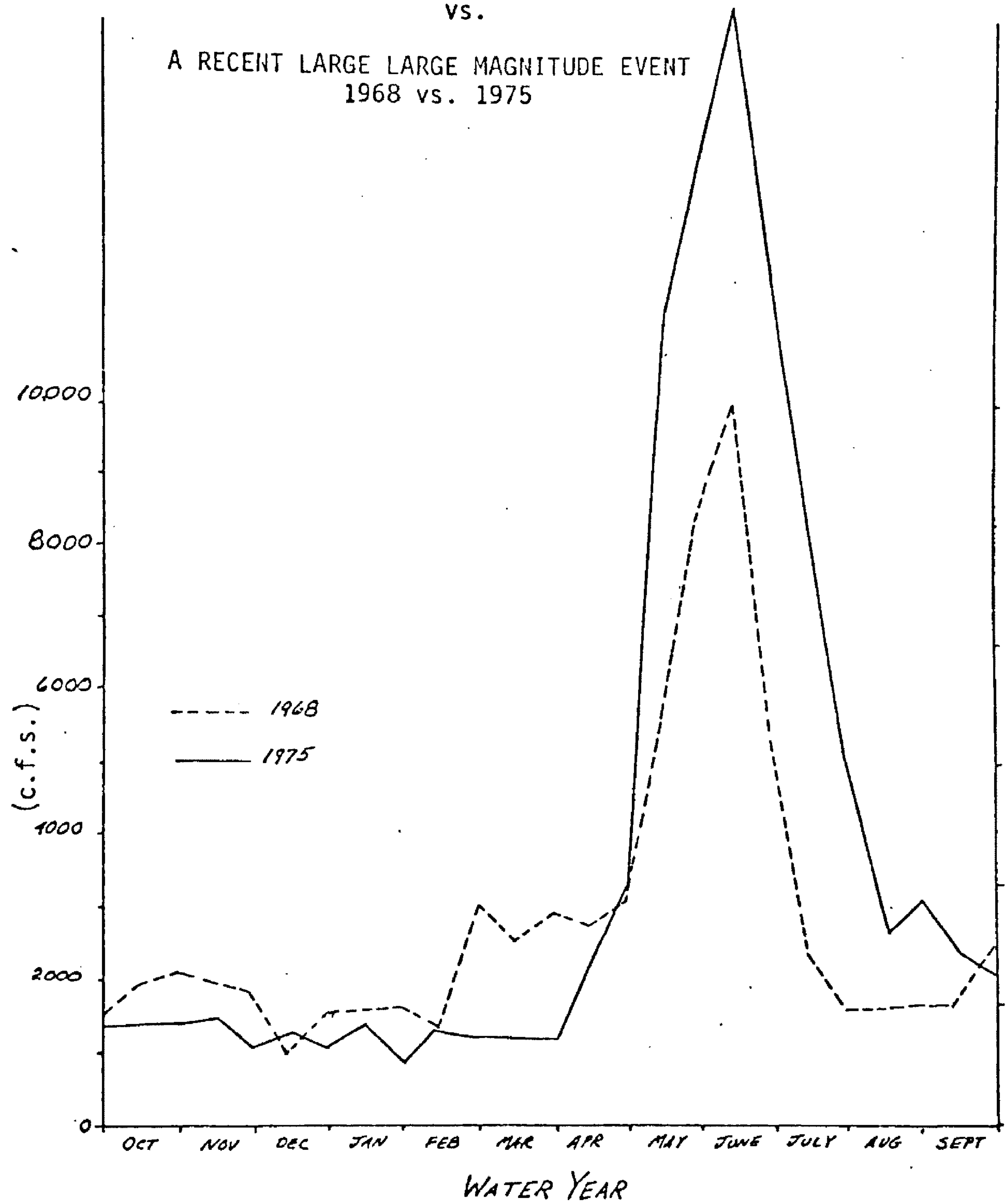
APPENDIX V

Clark Fork River Flow Relations

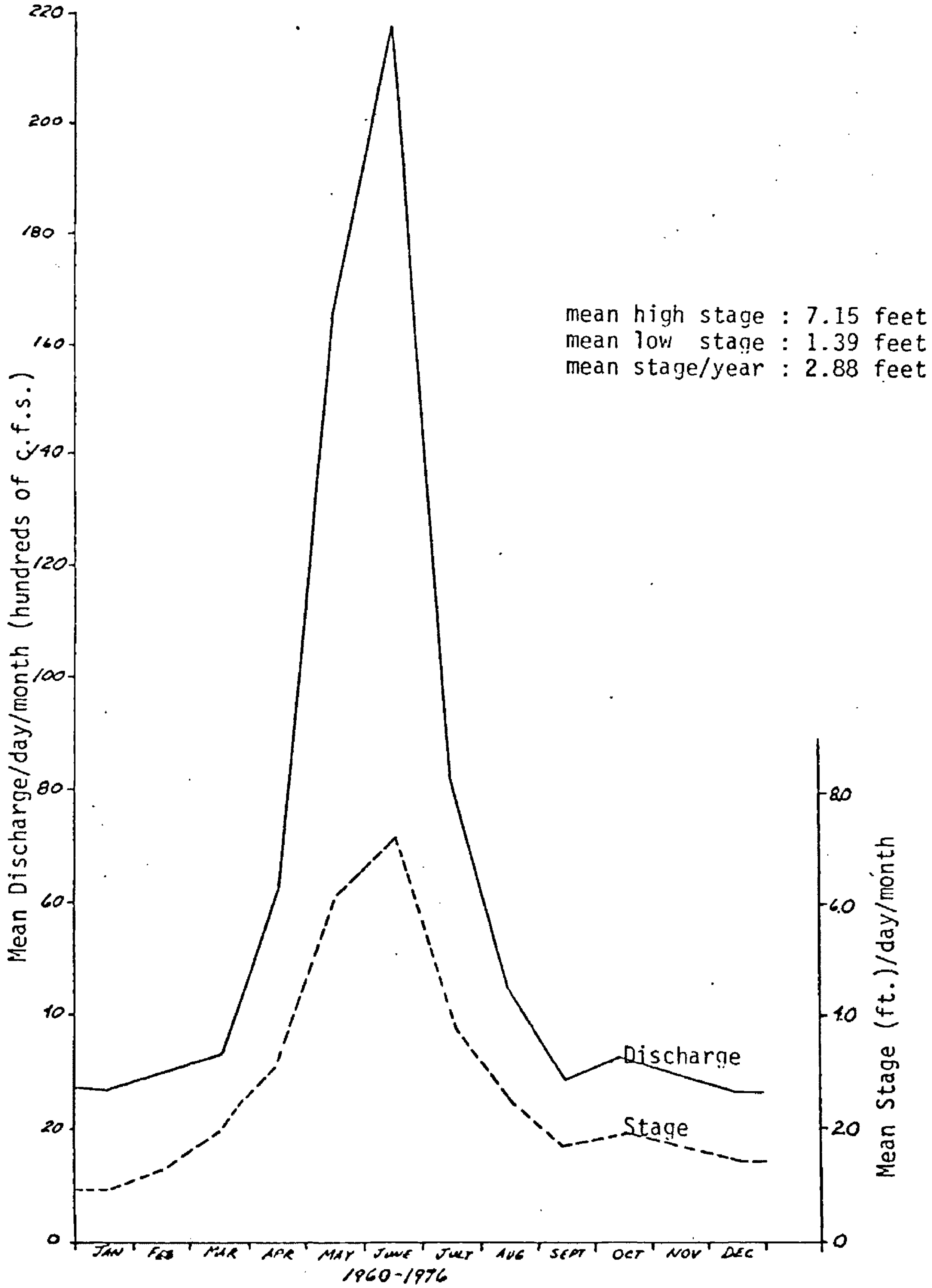
HYDROGRAPHS OF MEAN YEAR

VS.

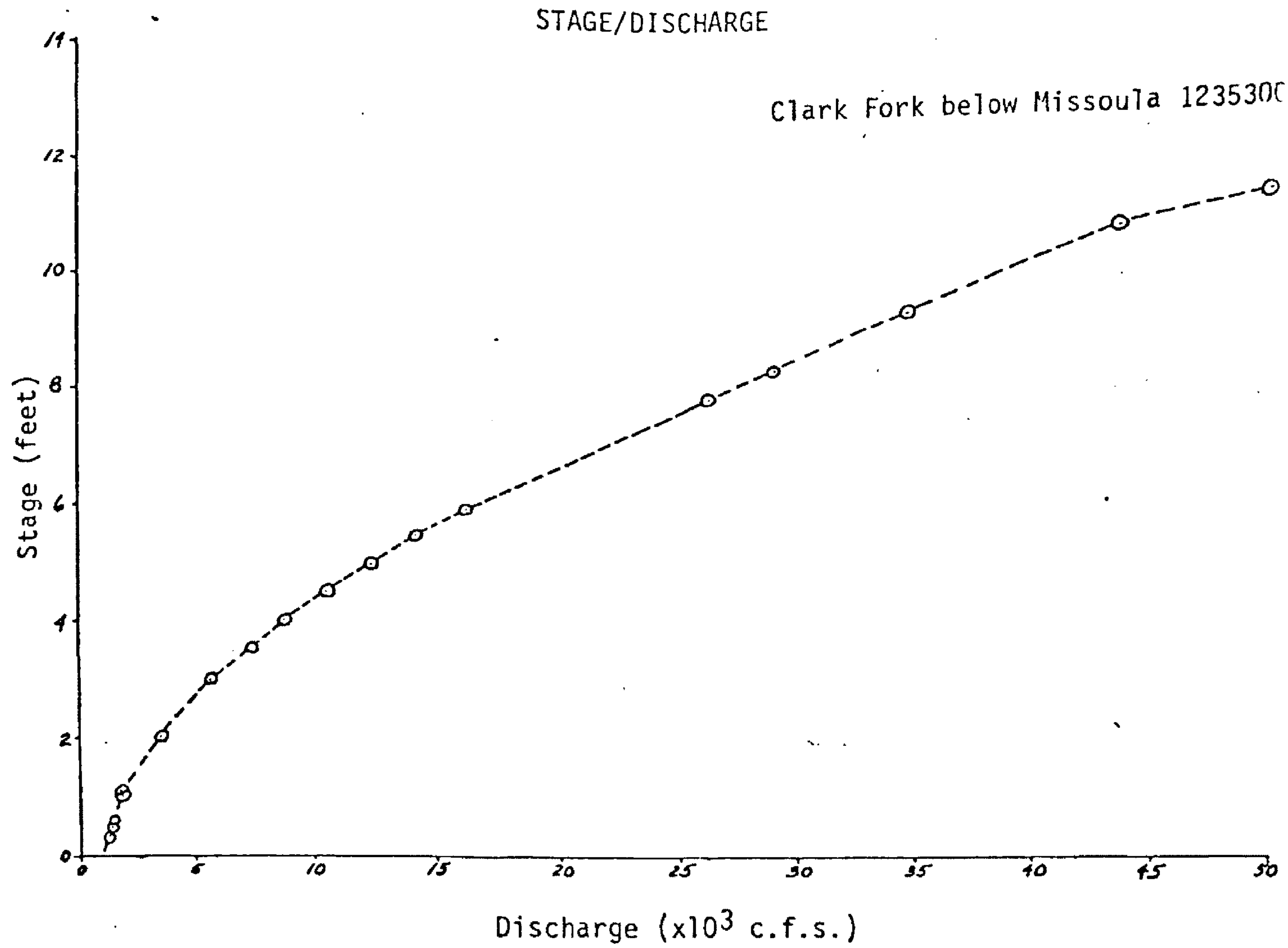
A RECENT LARGE LARGE MAGNITUDE EVENT
1968 vs. 1975



Clark Fork above Missoula
#12-3405



Clark Fork River below Missoula


STAGE/DISCHARGE
Clark Fork below Missoula 123530C
Stage (feet)
Discharge (x10³ c.f.s.)
0
2
4
6
8
10
12
14
0
5
10
15
20
25
30
35
40
45
50

APPENDIX VI

Montana Power Company
Water Use Data

Taole VI-1: Montana Power Company Water Use Data
Missoula Water Department
Customer Class Usage
1975

Customer Class	Pércent of Total	Annual Use 100 c/Year	Max. Day Use Factor %	Max. Day Use 100 cf/ Day	Max. Hour Use Factor %	Max. Hour Use 100/cf/ Day
METERED SERVICE						
General Service	21.8%	1,945,724	207	14,3 6	3	20,450
UNMETERED SERVICE						
Residential						
Unmetered	7.1%	6,809,600	203	38,336	251	47,475
Domestic & Misc.		4,624,500	120	15,848	150	19,841
Sprinkling		2,185,000	376	22,506	462	27,634
MPC Employees Unmetered	.6%	50,500	207	283	254	347
Commercial and Industrial						
Unmetered	.5%	50,050	665	910	1,435	1,967
Private Hydrants		50	5,150	705	12,350	1,692
Others		50,000	150	205	200	275
Governmental and Municipal						
Unmetered	1.0%	87,250		5,028		11,194
City of Missoula Hydrants		100		4,108		9,859
Park Sprinkling		47,000		520		650
Sewers & Streets		40,150		400		685
Total Water Sales	100.0%	8,943.025	221	58,953	332	81,433
Unaccounted For		2,099,847	100	5,753	100	5,753
Total Gravity and Pump Flow (w/o Hydrant Capacity)		11,042,721	198	59,893	250	75,635
Total Capacity		11,042,871	214	64,706	288	87.186

Note: All unmetered water usages are estimates

Table VI-2
THE MONTANA POWER COMPANY
MISSOULA WATER DEPARTMENT
Customer Summary and Projections

Year	Number of Customers at End of Year													Total		
	Residential			Commercial-Industrial			Public			Miscellaneous						
Actual	Metered	Unmetered	Total	Metered	Unmetered	Total	Metered	Unmetered	Total	Metered	Unmetered	Total		Metered	Unmetered	Total
1962	359	9,509	9,868	503	166	669	41	445	486	105	58	163		1008	10,178	11,186
1963	449	9,649	10,098	512	157	669	41	447	488	110	62	172		1112	10,315	11,427
1964	591	9,744	10,335	526	152	678	42	452	494	118	54	172		1277	10,402	11,679
1965	725	9,935	10,660	559	153	712	42	457	499	119	47	166		1445	10,592	12,037
1966	863	9,798	10,661	578	156	734	44	465	509	121	58	179		1606	10,477	12,083
1967	974	9,897	10,871	591	152	743	47	479	526	123	71	194		1735	10,599	12,334
1968	1076	9,992	11,068	617	146	763	49	483	532	124	74	198		1860	10,695	12,561
1969	1135	10,096	11,231	625	145	770	49	530	579	124	78	192		1933	10,849	12,782
1970	1403	10,327	11,730	653	145	798	50	568	618	140	77	217		2246	11,117	13,363
1971	1482	10,519	12,001	691	147	838	50	595	645	142	76	218		2365	11,337	13,702
1972	1568	10,550	12,118	734	157	891	51	602	653	148	82	230		2501	11,391	13,892
1973	1716	10,646	12,362	760	158	918	51	590	641	148	85	233		2675	11,479	14,154
1974	1894	10,700	12,594	800	158	958	66	626	692	162	92	254		2922	11, 76	14,498
1975	2055	10,797	12,852	818	173	991	66	629	695	164	92	256		3103	11,691	14,791
1976	2190	10,596	12,786	813	173	986	72	638	710	164	95	259		3239	11,502	14,741
Projected																
1977	2330	10,600	12,930	840	178	1018	79	648	727	168	99	266		3417	11,525	14,942
1978	2470	10,600	13,070	867	183	1050	87	658	745	172	103	272		3596	11,544	15,140
1979	2610	10,600	13,210	894	188	1082	94	668	762	177	107	280		3775	11,563	15,338
1980	2750	10,600	13,350	921	193	1114	102	678	780	181	111	286		3954	11,582	15,536
1981	2890	10,600	13,490	948	198	1146	109	688	797	185	115	293		4132	11,601	15,733
1982	3030	10,600	13,630	975	203	1178	116	698	814	189	119	300		4310	11,620	15,930

Note: Residential Customer Class Includes: Residential
Commerical-Industrial Customer Class Includes: Stores, stores and residences (flats), office buildings, apartment houses, hotels-motels, garages, service stations, cafes, creameries, factories and warehouses, laundries.
Public Customer Class Includes: Schools, public miscellaneous, hospitals, public hydrants.
Miscellaneous Customer Class Includes: Fire sprinklers and hydrants, misc.

Table VI-3
THE MONTANA POWER COMPANY
MISSOULA WATER DEPARTMENT

Top Thirty-four Government/Commercial/Industrial Metered Water Users
Ranked by 1976 Consumption

Rank	Major Users	Meter Size(s)	Annual Consumption (100 Cu.Ft)	Annual Revenue (Whole Dollars)	Average Revenue Per 100 Cu. Ft. (Cents)
1	University of Montana	14"(1);6"(4)	430,317	$ 15,033.62	3.49¢
2	Intermountain Lumber Comapny	8"(2);1"	100,433	7,810.36	7.78
3	Travois Village	8"	47,497	3,717.27	7.83
4	St. Patricks Hospital	4"	45,244	3,823.25	8.45
5	School District(3 High; 14 Grade)		32,000(est.)*	5,440.00	17.06
6	Village Motor Inn	3";2"(3)	24,912	2,747.40	11.03
7	Community Hospital	4"	23,918	2,400.50	10.04
8	Burlington Northern Ry.	6";3"	13,124	1,772.30	13.50
9	Holiday Inn	2";(2)	12,876	1,817.66	14.12
10	Coca Cola Company	4"	11,226	1,425.00	12.69
11	Missoula Laundry	3"	8,168	1,139.88	13.96
12	Eagles Manor(Missoula Manor House)	4"	7,356	1,075.60	14.62
13	Hotel Florence Motor Inn	2"	6,186	891.36	14.41
14	Pepsi Cola Bottling	2"	6,160	901.20	14.63
15	Missoula General Hospital	2"(2)	5,848	987.99	16.89
16	Travelodge Motel	2"	5,453	816.36	14.97
17	North Star Trailer Court	1"	5,325	794.09	14.91
18	Meadow Gold Dairy		4,342	699.60	16.11
19	Missoula County Courthouse	4"	4,248	725.04	17.07
20	Lolo View Trailer Court	2"	3,987	637.53	15.99
21	4 B's Cafeteria	1"(2)	3,660	596.76	16.30
22	Hospital	2"	3,238	464.44	14.34
23	City of Missoula		3,210	756.00	23.55
24	Stockman's Bar		2,944	515.28	17.50
25	1600 Cooley Trailer Court		2,734	586.77	21.46
26	U.S. Post Office	4";2"(2)	2,645	596.64	22.56
27	2 J's Produce - Ronan Street	2"	2,445	451.06	18.45
28	Federal Building(Old Post Office)		2,322	435.30	18.75
29	Leisure Highlands Golf Course & Mansion	4"	1,995	386.52	19.37
30	Montana Bell Telephone	2"(2)	1,670	495.87	29.69
31	Alpha Arms Apartments-775 Monroe	2"	1,589	328.35	20.66
32	Missoula Rehabilitation Center	2"	863	229.80	26.63
33	Montana State Highway Department	2"(2);1"	788	180.00	22.84
34	Missoula County Health & Welfare	2"	571	208.86	36.58
	Total for Top 34 Water Users		829,294	$60,887.66	7.40¢
	Total for All Metered Gov't/Comm./Ind/Water Users		1,328,748	198,619.98	14.95¢
	Top 34 Gov't/Com./Ind/Water Users as Percent Total		62.41%	30.65%	

()Number of Meters for Each Size.
* Based on Actual Consumption Data for Three High Schools & Six Grade Schools; Eight Smaller Grade Schools Estimated.